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INTERIOR WIRING

AND SYSTEMS FOR

ELECTRIC LIGHT AND POWER SERVICE

A MANUAL OF PRACTICE
FOR
ELECTRICAL WORKERS, CONTRACTORS,
ARCHITECTS AND SCHOOLS

BY

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PREFACE

This book is intended as a guide to modern practice in electric lighting and power applications, and in the design and installation of the wiring for such purposes.

It has been written particularly for electrical workers who wish to become familiar with good practice in these branches of the electrical industry. The information presented is intended especially for superintendents and operators of electrical installations and for wiremen, who may be called upon to make extensions to or changes in existing installations, and who need definite information as to the best method of procedure. This book is also adapted for use in schools giving trade courses in electric wiring, to supplement the instruction given in the shop. It should also be useful for architects, when planning electrical installations. The tables in Appendix A and the methods of calculating wiring circuits will be of particular service to electrical contractors, when laying out new work.

There are many text-books which deal with the principles of operation of electrical apparatus and the methods of calculating electric circuits, but the usual electrical worker or the student does not possess a sufficient background of practical experience to enable him to use these principles to design a wiring installation. The attempt has been made here to take up these subjects where they are left by the text-books and to supply information which will compensate, in part at least, for a lack of practical experience. The intention has been to make the information as complete as possible so that the user may have sufficient data to meet his needs. Accordingly, lighting and power applications are covered in Parts I and II in such a way that the reader can gain an idea of the types of lamps and motors available, and the proper applications of each type. Simple rules are given for deter-

mining the size and arrangement of lighting units and for determining the sizes of motors required for various kinds of service. Following this, in Part III, is a description of apparatus and fittings for interior wiring, together with detailed methods of calculating the sizes of circuits to meet various requirements. The examples given in the last chapter illustrate and describe typical lighting and power applications and are reproduced from actual installations. Throughout the book, examples are included to illustrate each step. The calculations are taken up in detail, from the switchboard to the lamps, and the method of planning each part of the circuit is explained. This is carried out completely for each system—two-wire, three-wire, three-phase and two-phase.

This method requires the use of a large amount of detailed information and involves the use of definite rules of procedure. While, sometimes, these methods cannot be used without considerable modification, there is so much similarity in the usual industrial applications that generally their use will give satisfactory results. To assist in making an intelligent application and to guard against improper use of the data given, the limitations existing in each case are carefully stated. Explanations are also given of the performance of different lamps and motors under various conditions so that satisfactory applications may be secured

No attempt has been made to explain, in detail, the theory of operation of the various motors, as it would be beyond the scope of this book. Because it is written for "practical men," only simple mathematics have been used in the calculations. The methods employed for alternating-current circuits are therefore somewhat limited in their application. For the usual problems met with in practice, however, they are entirely satisfactory and care has been taken to point out such limitations as exist, so that the user may know whether or not these methods can be safely employed.

Free use has been made of illustrations and diagrams, most of which have been drawn especially for this book. In describing apparatus, it has been necessary to use many illustrations furnished by electrical manufacturers. It would obviously be impossible to show a complete line of apparatus because of the great variety on the market. The fact, therefore, that only a single illustration, typical of many products

available, has been given, should not lead the reader to conclude that similar apparatus made by other manufacturers is not as good. The intention has been to illustrate each *type* of apparatus only, leaving the reader to obtain detailed information on a particular line of apparatus from trade catalogues. With a few exceptions, the tables in Appendix A were prepared especially for this book. They are intended to be "working tables" which can be used to save long computations and to give definite information on the various problems involved in the lighting and power applications. A few of these tables and the chart for the calculation of voltage drop were first published by the author in the magazine *Power* and are reproduced here by permission.

Thanks are due the numerous manufacturing concerns that have assisted by furnishing illustrations or performance information, and particularly to the Westinghouse Electric and Manufacturing Co., the General Electric Co., the Cooper Hewitt Electric Co., and Westinghouse, Church, Kerr & Co. The author has tried to make the information presented as complete and accurate as possible. He will appreciate any suggested improvements or notices of errors in the data given.

ARTHUR L. COOK.

BROOKLYN, NEW YORK,
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PART I. ELECTRIC LIGHTING SYSTEMS

CHAPTER 1

INTRODUCTION

1. Methods of Producing Artificial Light. In general, light is produced by heating a solid or gaseous body to a high temperature, although this is not always necessary, as is shown by the action of vacuum-tube and mercury-vapor lamps. When a body is heated, it gives off heat as well as light, and sufficient energy must be supplied to produce both of these effects. For a high light-producing efficiency, the heat energy (which is wasted) must be as small as possible.

2. Efficiency of the Electric Light. As a substance is heated, the color of the light produced changes from red to white as the temperature increases, and the light efficiency increases very rapidly. High efficiency therefore necessitates operation at high temperatures.* It is difficult, however, to find substances which will withstand the required high temperature without melting or vaporizing. The high efficiency of the tungsten lamp results from the high temperature at which the filament may be operated without rapid deterioration. The high efficiencies obtainable from arc lamps are possible only because of the very high temperature of the electric arc. In spite of all that has been done to improve this efficiency, the amount of energy given off in the form of light from a "gas-filled" tungsten lamp is only about 3.5 per cent of the total

* Except as noted in paragraph 1.

amount of energy supplied to the lamp. The remainder of the energy disappears in the form of heat. This lamp is the most efficient type of incandescent lamp and is exceeded in efficiency only by certain kinds of arc lamps which convert about 4.5 per cent of the energy into light.*

3. Classes of Lamps. Incandescent lamps produce light by the heating effect of an electric current traversing a solid conductor, and always operate at a high temperature. In **arc lamps,** the current passes through a gaseous conductor, and the light proceeds either from the gas or from the solid terminals where the gaseous column makes connection with the circuit. The production of light by means of the electric arc is accompanied by a very high temperature, except in vacuum-tube lamps and some forms of the mercury arc.

4. Types of Lamps. There are a number of types of both incandescent and arc lamps. Paragraph 5 gives a tabulation of the usual types employed for artificial illumination and indicates the character of service for which they are best suited. The system of current supply, whether alternating or direct current, is also specified. The column headed "lumens per watt" gives an indication of the relative efficiency of the various lamps, since it shows the amount of light produced per watt input. The most efficient lamp is not necessarily the best for a particular purpose, since other considerations such as quality of light and size of unit must be given proper weight when selecting the type of lamp to be used. The applications for which each of the lamps listed in paragraph 5 is best adapted will be given in succeeding chapters.

* Including losses in lamp mechanism.

5. Types of Electric Lamps.

Name.	Service.	Lumens per Watt.*	Suitable for:
Incandescent Lamps			
1. Carbon filament	A.C. or D.C.	3.49	Interior use. Local lighting.†
2. Metallized filament (Gem)	A.C. or D.C.	4.15	Interior use. Local lighting.†
3. Tantalum filament	A.C. or D.C.	5.54	Interior use. Local lighting.†
4. Tungsten. Vacuum type. (Mazda B)	A.C. or D.C.	10.32	Interior use. General or local lighting.
5. Tungsten. Gas-filled type (Mazda C)	A.C. or D.C.	21.80	Interior or general lighting, outdoor use. Street lighting.
Arc Lamps			
6. Open, carbon arc	D.C.	12.30	Outdoor use. Street lighting.
7. Enclosed, carbon arc	A.C. or D.C.	7.35	Interior or general lighting outdoor use. Large areas.
8. Flame-arc	A.C. or D.C.	28.00	Interior or general lighting. outdoor use. Large areas.
9. Metallic-electrode‡	D.C.	23.40	Outdoor use. General lighting. Large areas.
10. Mercury-vapor arc Low-pressure type	A.C. or D.C.	13.10	Interior use. General lighting. Large areas.
11. Mercury-vapor arc Quartz-tube type	D.C.	20.30	Interior or general lighting. outdoor use. Large areas.

* For explanation of this term see Chapter 4. Values given are approximate, as they vary slightly with the size of lamp.

† These lamps are not very commonly used at present.

‡ Sometimes called "metallic flame" or "luminous arc."

CHAPTER 2

INCANDESCENT LAMPS

6. General Principles. In Chapter 1 it was pointed out that efficient light production by means of incandescent lamps is accompanied by a very high temperature of the light-producing conductor or filament. This filament, therefore, must be composed of a substance which will have a high melting-point, and which will not evaporate too rapidly at temperatures below the melting-point. Evaporation causes blackening of the glass bulb and also the gradual disintegration of the filament until it breaks. Evaporation must therefore be reduced to a low value for successful operation. Furthermore, the resistance of the filament material should be high, so that filaments for commercial voltages will have reasonable lengths and diameters.

7. Construction. The filaments of all the commercial incandescent lamps now commonly used are enclosed in a glass bulb, from which all traces of air are excluded; otherwise the filament would rapidly oxidize and be destroyed. In some styles of lamp, a high vacuum is produced in the bulb; in others, it is filled with nitrogen or a similar gas which will not affect the filament. Connection is made to the filament by "lead-in-wires" which are sealed into the glass bulb. The lead-in-wires are attached to suitable insulated contacts forming the **base** of the lamp.

8. Life. The life of an incandescent lamp is expressed as the number of hours of burning at rated voltage before the filament disintegrates and breaks. Since it is impossible to build lamps which will all last exactly the same number of hours, an average value must be used. This is called the **rated life.** The actual life of individual lamps may be greater or less than this. At one time the term **useful life** was used extensively. This was taken as the number of hours burning before the candlepower dropped to 80 per cent of the original

value. This method of rating is no longer used to any extent, since most modern incandescent lamps do not decrease to 80 per cent of the original candlepower before they burn out. The life of a lamp depends upon the temperature at which the filament is operated. A very high temperature results in a high efficiency and gives a better color of light, but causes rapid blackening of the bulb and disintegration of the filament and therefore a short life. A low temperature has the opposite effect. The normal operating temperature is therefore chosen at such a point as to give the highest efficiency consistent with a reasonable life of the filament. The temperature depends upon the voltage applied, a voltage above normal giving an increase in temperature and consequently higher efficiency, whiter light and shorter life. The reverse occurs with voltages below normal. Filaments having a hot resistance greater than the cold resistance (such as gem, tantalum, and tungsten filaments) are less sensitive to voltage changes than the ordinary carbon filament, which has a hot resistance less than the cold value.*

9. Rating. Constant-potential or multiple lamps are rated at the normal operating voltage and the watts consumed at that voltage. Constant-current or series incandescent lamps are rated at the normal operating current and the candlepower (mean horizontal) produced at that voltage.

10. Power Consumption. Incandescent lamps are given a commercial rating in watts per candle to facilitate a comparison of the efficiency of various types and sizes. Either the mean horizontal candlepower† or the mean spherical candlepower † is used when stating the power consumption. The mean horizontal candlepower was generally used for this purpose until recently, but at present the mean spherical candlepower is used in rating most types of tungsten lamps. The power consumption, expressed in watts per candle, was at one time commonly called the "efficiency" of the lamp, but this is an incorrect use of the term and should be avoided. An incandescent lamp which consumes 400 watts and produces 445 candlepower has a commercial rating of $400 \div 445 = 0.90$ watt per candle. A lamp which consumes 400 watts and gives 534 candlepower would have a rating of 0.75 watt

* See paragraph 34.

† See paragraph 66.

per candle. The second lamp would, of course, be more efficient than the other because it requires less power to produce one candlepower. The power consumption is also frequently specified in terms of the amount of light produced (lumens).* Thus we may say that a lamp consuming 100 watts and giving a total light output of 1032 lumens has a specific output of $1032 \div 100 = 10.32$ lumens per watt. While the quantities, "lumens per watt" or "watts per candle" do not express the true efficiency of the lamp, we can compare the efficiencies of two lamps by comparing the power consumption of each.

Thus the tungsten lamp taking 1.00 watt per candle is said to be more efficient than the metallized-filament lamp requiring 2.5 watts per candle. A more correct way to express the relative efficiency is to compare the amount of light produced by one watt. Thus the metallized-filament lamp produces about 4.15 lumens per watt and the tungsten lamp about 10 lumens per watt. We can therefore say that the tungsten lamp is more than twice as efficient as the metallized-filament lamp.

11. Bases. At the present time, in the United States, practically all lamps are provided with the "Edison" screw-type base, which has been adopted as standard. This base is made in three sizes: **mogul**, which is $1\frac{1}{2}$ inches in diameter; **medium**, $1\frac{1}{32}$ inches in diameter; and **small**, including candelabra bases $\frac{7}{16}$ inch in diameter and miniature bases $\frac{3}{8}$ inch in diameter. **Mogul bases** are used for street-lighting systems and for the larger types of multiple lamps. The **medium base** is the ordinary style used with incandescent lamps for 110- or 220-volt circuits, and the **small bases** are, in general, used for low-voltage lamps and special work. In some cases bayonet-type bases are used where excessive vibration occurs, as in automobile lighting systems. For large-size lamps the **skirted base** is used. This is shown in Fig. 3. The skirted base may be obtained for both medium and mogul sockets.

12. Frosted Lamps. Incandescent lamps are sometimes frosted when they are to be used without shades and where the clear lamp would be objectionable. With a frosted lamp, the entire bulb becomes luminous and the filament is not visible, thus reducing the intensity of the light. Lamps may be frosted by sand-blast or acid, but in either case the surface

* See Chapter 4 for explanation of this term.

of the glass is left rough, making it difficult to keep clean. Frosting solutions are available which give a smooth surface, but these are not as permanent as the other methods and should not be used in locations exposed to the weather. Lamps are frequently **bowl-frosted,** that is, only the lower half of the bulb is frosted. These lamps are very commonly used with reflectors to shield the lower part of the filament from view. The **rated life** of a frosted lamp is the same as a clear lamp, but the **candlepower** falls off more rapidly. A frosted lamp absorbs about 8 per cent of the light produced, and declines in candlepower about twice as rapidly as a clear lamp. A bowl-frosted lamp absorbs about 5 per cent of the light.

13. Colored lamps are used for signs and various decorative purposes. Lamps made from colored glass are expensive and are seldom used. Generally clear lamps are dipped in a coloring solution or the bulbs are covered by "color caps." These are small glass globes which fit over the lamp. They are used for signs and are more satisfactory than dipped lamps, which will not withstand severe weather conditions. Colored lamps are much less efficient than the clear lamps because a large part of the light produced is absorbed and wasted. A special form of gas-filled tungsten lamp is made with a blue glass bulb, which is so designed as to correct the color value of the light and produce an effect closely resembling daylight. This results in a considerable loss of light, but because of the very high efficiency of this type of lamp, it is a thoroughly practical method to use where true daylight effects are required.

14. Effect of Alternating Current. Incandescent lamps may be used on either direct or alternating current. With the exception of the tantalum lamp, there does not seem to be any appreciable difference in the life of the lamp when used on either system. The life of the tantalum lamp is very much less on alternating current. If incandescent lamps are operated on a low-frequency alternating-current circuit, there is a noticeable flickering of the light.*

15. Color of Light. The color of light produced by an incandescent lamp depends upon the temperature. As the temperature is increased, the color becomes more nearly white. The carbon lamp operates at the lowest temperature, about 1950° Cent. (3450° Fahr.) and gives a decidedly yellow light.

* See paragraph 71.

The vacuum-type tungsten filament operates at a temperature of about 2100° Cent. (3810° Fahr.) and the gas-filled tungsten filament at about 2400° Cent. (4350° Fahr.). The gas-filled tungsten lamp therefore produces the whitest light. Incandescent lamps may be arranged in order of their color value as follows: carbon, metallized-carbon, tantalum, vacuum-type tungsten and gas-filled tungsten.

16. Distribution of Light. Incandescent lamps used without reflectors give the maximum candlepower in a horizontal direction, as may be seen by referring to Fig. 20, which gives the candlepower measured at various points above and below the center of the lamp.* For this particular lamp the horizontal candlepower is 96, while directly below the lamp it is only 30 candlepower. The distribution varies with the particular arrangement of filament used.

Carbon-filament Lamps

17. Construction. This lamp was the earliest commercial form of incandescent lamp. It employs a filament of specially prepared, dense carbon, operating in a high vacuum.

18. Applications. Carbon lamps have a very restricted use at present because of the many advantages of the more efficient types of incandescent lamps. They are used to a certain extent for electric signs, although tungsten lamps are more commonly used for this purpose. For 220-volt circuits, carbon lamps are sometimes used when small units are required. The use of carbon lamps for general illuminating purposes is practically discontinued. The advantages of the carbon lamp are low first cost and extreme ruggedness. The disadvantages are low efficiency and poor quality of light.

19. Standard Sizes. For 110-volt circuits, the sizes range from 20 to 60 watts, and for 220 volts from 35 to 60 watts. The power consumption is from 4.2 to 3.0 watts per candle.† Sign lamps are made in sizes from 10 to 30 watts with a power consumption of from 4.0 to 6.0 watts per candle.† The rated life of carbon lamps is about 700 hours.

* See paragraph 67 for explanation of curves.

† Mean horizontal candlepower.

Metallized-filament Lamps

20. Construction. These lamps use a modified form of carbon filament. By a special heat treatment in the electric furnace, the ordinary carbon filament is changed into a **metallized carbon** which has the appearance of very dense graphite. The filament is operated in a vacuum the same as an ordinary carbon lamp.

21. Applications. The commercial metallized-filament lamp is called the Gem lamp. A few years ago this lamp rapidly replaced the ordinary carbon lamp for general illuminating purposes, and it has now in turn been replaced to a large extent by the tungsten lamp. It is at present used very little for general illumination and finds its chief application as a substitute for small-size carbon lamps where great ruggedness and low cost are required. It is especially adapted for portable lights in industrial establishments. It cannot compete with the tungsten lamp for general illumination unless the cost of power is very low—below 1 cent per kilowatt-hour.

22. Standard Sizes. Table I gives data on the principal sizes of Gem lamps which are now produced. The power consumption of the Gem lamp is about 2.5 watts per candle,* but this varies somewhat, as may be seen from the table. The filament has a hot resistance about 2.5 times its cold value.

Tantalum Lamps

23. Construction. The filament of this type of lamp is made from metallic tantalum, and is operated in a vacuum. The metal tantalum has a very high melting-point and can be operated at a high temperature, but the resistance is low, and therefore, for ordinary voltages, the filament length must be great and the cross-section very small. The filament is wound in a zig-zag manner between special supports.

24. Applications. A few years ago, the tantalum lamp was widely employed for general illuminating purposes, but the tungsten lamp, which was introduced shortly afterwards, very soon displaced the tantalum lamp, which at the present time is little used. Until the development of the wire-drawn tungsten

* Mean horizontal candlepower.

filament the tantalum lamp was more rugged than the tungsten lamp, and this was one reason for its extensive use.

25. Standard Sizes. Tantalum lamps could at one time be obtained for both 110- and 220-volt service in sizes ranging from 25 watts to 80 watts, but they are no longer manufactured in this country. The lamps take about 1.8 watts per candle and have a useful life of 800 hours on direct current. On 60-cycle current, however, the life is only about 300 hours.

TUNGSTEN LAMPS—VACUUM TYPE

26. Construction. The filament of tungsten lamps is composed of pure metallic tungsten. Originally the filament was made from a paste containing powdered tungsten, but at present all the filaments are of the drawn-wire type. These filaments are made by drawing tungsten through dies, using diamond dies for the finishing. Filaments made from powdered tungsten were extremely fragile and consisted of several hairpin loops connected in series. The wire-drawn filament is composed of one continuous length of tungsten wire looped around suitable supports and is very strong. Fig. 1 shows the ordinary type of tungsten lamp. For some purposes it is necessary to concentrate the filament. To accomplish this, the tungsten wire is wound in the form of a very small helix or single-layer coil, thus reducing the space occupied by the filament (Fig. 2). This type of construction is sometimes used for vacuum type lamps and is always used for gas-filled tungsten lamps. The tungsten wire, after being drawn through dies and before it is heated in the bulb, has a tensile strength greater than steel and can be readily bent or wound into spirals. After the lamp has been operated for a short time, the wire-drawn filament becomes more brittle, but it is still much superior to the old type of filament, and has sufficient strength to be used where there is considerable vibration, as in the lighting of electric cars. In order to prevent blackening of the bulb, due to evaporation from the filament, a special chem-

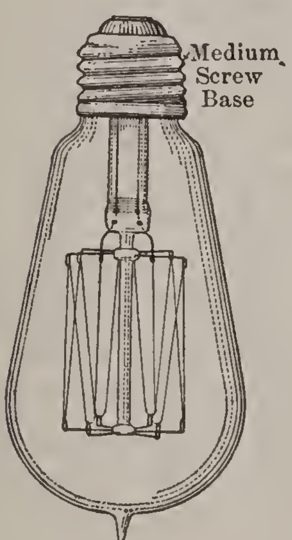


FIG. 1. — Tungsten Lamp, Vacuum Type.
(40-watt, Mazda B.)
($\frac{1}{4}$ scale.)

ical, called a getter,* is placed in the bulb. This combines with black particles given off from the filament and changes them to a transparent substance which does not cut off the light when deposited on the bulb. A very high vacuum is used with this type of lamp. The diameter of the filament of the tungsten lamp depends upon the current to be carried, and varies from about 0.0006 inch for the 10-watt, 110-volt size, which takes 0.091 ampere, to about 0.020 inch for a series lamp taking 20 amperes. The length of the filament depends upon the voltage. The filament of a low-voltage lamp of a given watt rating is larger in diameter and shorter than the filament for a high-voltage lamp of the same rating in watts. This is apparent when we recognize that the low-voltage lamp must carry a larger current (for the same watts) than the high-voltage lamp.

27. Applications. The tungsten lamp is now the most widely used of all the types of incandescent lamps, about 80 per cent of all lamps used at present† being of this type. It is adapted for any service where incandescent lamps are required, except when they are subjected to very rough usage, such as portable lamps. The principal field of usefulness of the vacuum-type lamp for general illumination purposes is in sizes below 100 watts, the gas-filled lamp being generally preferable for larger sizes. Vacuum-type tungsten lamps are also widely used for railway car lighting, electric signs, automobile lighting, and for flash-lamps. The wire-drawn filament is strong enough to allow the successful use of 110-volt tungsten lamps as small as 23 watts in the lighting of electric cars. Concentrated filament lamps, with reflectors, are used for stereopticon and small moving-picture machines, for automobile, locomotive and street-railway headlights and for flood lighting‡ of bill boards, building fronts, etc. The advantages of the tungsten, vacuum-type lamp are high efficiency, excellent color of light and adaptability for various classes of service. Compared with the Gem lamp, the tungsten lamp is somewhat more expensive, but its superiority in other respects justifies its use except for small units where power is very cheap; for example, below 1 cent per kilowatt hour or where the lamp would be subjected to very rough usage.

* Or "vacuum getter." † 1916.

‡ See paragraph 142.

28. Standard Sizes. The commercial, vacuum-type tungsten lamps are known generally as "Mazda" or "Mazda B" lamps. These names are applied to the lamps made by most of the lamp manufacturers in this country, although there are a few manufacturers, producing lamps under different patents, who use other names. Mazda lamps can now be obtained for any voltage or service for which incandescent lighting is suited. Table 2 gives data on the commercial sizes of Mazda B lamps for multiple service and general illuminating purposes. While the lamps can be supplied for various voltages from 105 to 125 volts and from 220 to 250 volts, the exact operating voltage must, of course, be specified when ordering. The rated life of the ordinary multiple lamps is 1000 hours for most sizes. Stereopticon and headlight lamps have a short life varying from 220 to 500 hours. Sign lamps have a life of 2000 hours. The power consumption of vacuum-type tungsten lamps is at present about 1.28 watts per mean spherical candle.* There has been a continued improvement in this respect during the last few years, due to improvements in manufacture. The color of the light is entirely satisfactory for all general illuminating purposes, even where practically correct color values are important.

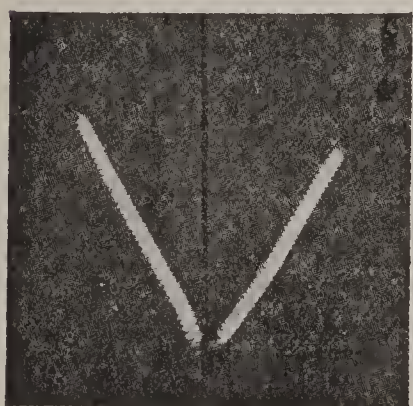


FIG. 2.—Enlarged View of Coil Filament for Tungsten Lamp.

View of a filament for a series type, 250-cp. lamp. For multiple lamps a longer filament of the same form is used. (National Lamp Works of G. E. Co.)

TUNGSTEN LAMPS—GAS-FILLED TYPE

29. Construction. The gas-filled type of lamp employs a wire-drawn tungsten filament operated in a glass bulb containing nitrogen or similar gas. The pressure of the gas when the lamp is lighted is about equal to the air pressure outside the bulb, so that there is no danger of the lamp exploding. As has been previously explained, the working temperature of an incandescent filament is limited by the tendency to rapid evaporation and blackening of the bulb if the temper-

* 1.0 watt per mean horizontal candle.

ature is made too high. The rate of evaporation increases rapidly as the temperature approaches the melting-point of the filament. This effect may be compared to the vaporizing of water at temperatures slightly below the boiling-point. If water is heated in a vacuum, it is well known that the boiling-point is very much reduced and in the same way the vaporizing effect will take place at a lower temperature. The use of a vacuum in an incandescent lamp, therefore, increases the amount of vaporization of the filament at a given temperature. If the filament is operated at ordinary atmospheric pressure, the temperature can be raised considerably higher before there is excessive evaporation. The filament could not be operated in the air, as it would oxidize or burn. If, however, the bulb is filled with nitrogen or a similar gas, there is no tendency to oxidize and the filament can be run at a higher temperature than for the vacuum-type of lamp. The presence of gas in the bulb results, however, in a cooling of the filament by convection currents, and to counteract this as much as possible, a concentrated filament is used.* The closeness of the coils results in a mutual heating effect and exposes a minimum amount of the filament to the cooling action of the gas. Fig. 3 illustrates the gas-filled type of lamp. It will be noted that this lamp is provided with a long neck, which assists in keeping the base, and socket cool. The mica baffie retards the circulation of the gas and also helps to keep these parts cool, Lamps of the smaller sizes are made with straight sides without the mica baffie and have the same general appearance as the vacuum lamps, Fig. 1. This style is most commonly used for street lighting service where there is thorough ventilation. Gas-filled lamps are most successful in the larger sizes, because small sizes of filament expose relatively more surface to the cooling effect of the gas. The vacuum-type lamp can be burned in any position, but the standard position

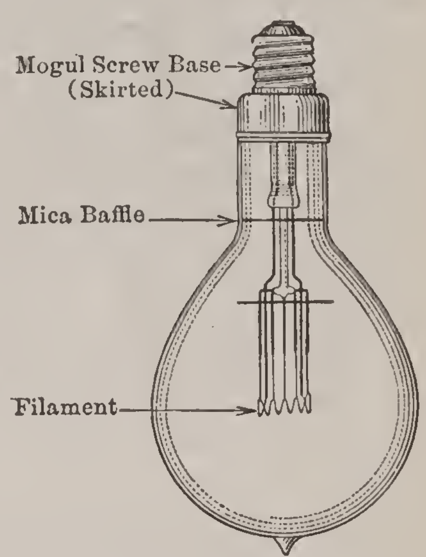


FIG. 3.—Gas-filled Tungsten Lamp.
(750-watt, Mazda C.) (1/8 scale).

* See paragraph 26.

for the gas-filled lamp is vertical, with the tip of the lamp down.* Lamps can be provided on special order which may be burned with the tip up. With the lamp burning in the normal position (tip down) the blackening of the bulb takes place principally in the upper part where it has little effect in shutting off the light.

30. Applications. Gas-filled tungsten lamps are particularly well adapted for interior illumination of large areas, for outdoor illumination of various kinds, and for street lighting, where they have already replaced large numbers of arc lamps. Because of the concentrated form of filament, they can be used very successfully with reflectors, for locomotive and street-railway headlights and for stereopticons and small moving-picture machines. Lamps with special glass bulbs are used in photographic work, and for show windows. The lamps are not suited for illuminating small rooms or rooms with low ceilings, because of the high candlepower of the commercial sizes. They are a very strong competitor of the various modern arc lamps and are rapidly replacing them for many purposes.

31. Standard Sizes. The commercial gas-filled tungsten lamps are generally known as "Mazda C" lamps and sometimes as nitrogen lamps. Table 3 gives data on the commercial sizes of these lamps for multiple service and general illuminating purposes. Gas-filled lamps for series, street-lighting circuits are manufactured for 5.5, 6.6, 7.5, 15.0, and 20.0 amperes in sizes ranging from 60 to 1000 candlepower, although the complete range of sizes is not made for each current rating. The rated life of the ordinary multiple lamps is 1000 hours. Series lamps have a rated life of 1350 hours. Headlight lamps have a life of 300 to 500 hours, depending upon the size. The power consumption is about 0.74 watt per candle† for multiple lamps and reaches 0.57 watt per candle† for large series type lamps. The manufacturers do not recommend the frosting of Mazda C lamps because of the additional heating.

32. Color of Light. The light from the gas-filled tungsten lamp is whiter than that from the vacuum-type lamp and more nearly approaches daylight than any other incandescent lamp. It is excelled in this respect only by certain types of

* Except for the 75- and 100-watt sizes, which can be burned in any position.

† Mean spherical candlepower. For mean horizontal candlepower, the values are 0.59 and 0.45 respectively.

arc lamps. The light is suitable for general illuminating purposes, even where color values are important. For very exacting service, such as color matching in paint and dye works, and for show windows, lamps with blue glass bulbs are used to reproduce daylight effects. These lamps are called **daylight Mazdas** and are not as efficient as the clear glass lamps.

33. Heating Effects. Over 95 per cent of the power supplied to an incandescent lamp is given off in the form of heat. With large tungsten lamps, the amount of heat is so great as to necessitate careful ventilation. While the heat produced by either the vacuum or gas-filled lamp is practically the same for the same watt rating, the distribution of the heat is entirely different in the two styles. With the vacuum-type lamp, the heat is uniformly distributed over the whole bulb, but with the gas-filled lamp, burning tip down (as is usual), the gas carries a large proportion of the heat up to the neck and base of the lamp. These parts are consequently hotter than other parts of the lamp, with resulting high temperatures for the lamp socket and reflector. It is therefore advisable to avoid sockets which employ wax compounds or fibre as a part of the insulation. The use of rubber-covered wire for connecting the sockets should in general be avoided. Where lamps are exposed to the weather, it is necessary to shield the lamp bulb so that rain and sleet cannot come in contact with the upper part of the lamp. This is particularly necessary with the large-size units where the bulbs are so hot that there is danger of cracking the glass if it becomes wet.*

34. Effects of Voltage Variation. Tungsten lamps of all kinds give their rated candlepower and consume their rated watts only at the particular voltage for which they are designed. In any installation, the rated lamp voltage should of course be the average operating voltage of the system, measured at the lamps. The effect of a change in voltage has already been explained in paragraph 8. With tungsten lamps, the changes are not as great as for carbon-filament lamps. With an increase of 1 per cent in voltage, the candlepower of tungsten lamps increases about 3.6 per cent and the life is decreased about 13 per cent. A decrease in voltage has the opposite effect.

35. Overshooting. The resistance of all tungsten lamp fila-

* See paragraph 86.

ments, when cold, is only about one-twelfth the hot resistance. When the lamp is first thrown on the circuit, this causes a sudden rush of current amounting to about five to eight times normal at the instant when the switch is closed. This is less than the value calculated from the cold resistance (about twelve times normal) due to the effect of the resistance and reactance of the circuit and the heating of the filament. The current drops very rapidly to practically normal value at the end of 0.02 second. The excess current lasts for so short a time that it would not blow fuses, but ordinary overload circuit breakers, if set close to the normal value of lamp load, would trip. This can be avoided, however, by introducing a small time-element in the tripping of the breaker. This current rush has also been known to melt the solder at the base of the lamp and fuse it into the receptacle. This occurs only with the larger sizes of lamps, when a loose contact is made with the circuit, due to vibration partly unscrewing the lamp. When a tungsten lamp is connected to a constant-potential circuit, the candlepower rises to its normal value much more quickly than a carbon lamp. This causes an effect which is sometimes called "over-shooting," because the candlepower seems to be higher than normal for an instant. Apparently, however, this is an illusion due to the very rapid rise of candlepower.* This effect is of value when using tungsten lamps for the flashing type of signs, as it allows more rapid flashing effects.

* *Electrical World*, May 25, 1912.

CHAPTER 3

ARC LAMPS

36. General Principles. When the two terminals of an electric circuit are brought together with a loose contact and then separated slightly, the heat produced at the moment of separation vaporizes a portion of the terminals and forms an electric arc. The temperature of the electric arc is about 4000° Cent. (7230° Fahr.), and therefore the terminals or **electrodes** must be capable of withstanding a high temperature without melting. Until recently all arc lamps employed carbon electrodes. At present, however, various metals and other substances are used. An arc between pure carbon electrodes is a pale violet in color and gives off very little light. The principal sources of light are the spots on the electrodes where the arc touches. With d.c. arcs, more light is given off by the tip of the positive carbon than by the negative, and it is for this reason that an ordinary d.c. arc lamp should always be operated with the top carbon positive, so that most of the light will be directed downward in a useful direction. With an a.c. arc, there is not this difference. In the new types of lamps the arc itself is rendered luminous by the use of various chemicals in the electrodes with a resulting gain in efficiency. The flame-arc lamps are of this type.

37. Construction. Arc lamps consist essentially of a pair of electrodes of carbon or other suitable material, arranged to be brought into contact and then separated a short distance. Since the terminals must be maintained a fixed distance apart, some kind of mechanism is required to constantly "feed" the electrodes together as they are consumed, as well as to bring them together to "strike" or start the arc. These operations are accomplished by solenoid magnets, connected in the lamp circuit, which operate a suitable clutch mechanism attached to one or both of the electrodes. Vapor-tube lamps,

which are also classed as arc lamps, do not require a feeding mechanism, but a device for starting must be employed in some cases. If arc lamps are used on series or constant-current circuits, they must also be provided with a suitable **automatic cutout** to short circuit the lamp and thus keep the main circuit closed if the carbons break, or if the lamp circuit is opened by the carbons being entirely consumed. For lamps used on multiple or constant-potential circuits no automatic cutout mechanism is required, but the lamp must have, in addition to the carbon feeding mechanism, **a steadying resistance**. This is required because of the unstable nature of the arc and the tendency of the current to increase with a decrease in voltage. The proper steadying action is produced by a resistance in the case of d.c. lamps, and by a reactance coil in the case of a.c. lamps, the latter being used because less power is lost than with a resistance. Some types of arc lamps have the arc freely exposed to the air, but the more modern lamps have the arc enclosed in a glass globe which is nearly airtight.

38. Rating. Constant-potential or multiple arc lamps are rated at the normal operating voltage and the current which the lamp requires at that voltage. Most types of these lamps may be adjusted to take a current slightly above or below normal. The lamps may also be adjusted to operate on any voltage within 10 per cent above or below normal. Constant-current or series lamps are rated at the normal operating current required. They can usually be adjusted to operate on currents slightly greater or less than the normal value. At one time arc lamps were rated in candlepower, but this rating is no longer used, since it is meaningless.

39. Power Consumption. The power consumption of arc lamps is specified commercially in watts per mean lower hemispherical candlepower.* This method of rating allows a comparison of the relative efficiency of two types of arc lamps, but should not be used for comparing arc lamps with incandescent lamps rated in watts per mean horizontal candlepower.* If the watts per mean spherical candlepower are used for comparison a true measure of the relative efficiencies is obtained, since the total light output is considered in measuring the candlepower. For this reason, statements of power consumption for both arc and incandescent lamps are now commonly

* See Chapter 4 for explanation of this term.

made in watts per mean spherical candlepower. We can also accurately compare the efficiency of two lamps by stating the output of light in lumens per watt. The power consumption is always based on the total watts consumed by the lamp, thus including the losses in the feeding mechanism and the steadying resistance.

40. Systems of Power Supply. Nearly all kinds of arc lamps can be built for operation on either a.c. or d.c. systems, but a lamp adapted for one system or for a particular frequency cannot be used on a different system. A.c. arc lamps, in general, are not satisfactory for use at frequencies less than 40 cycles, because of the flickering of the arc. The flame-carbon lamp, however, has been successfully used on 25 cycles. Variations of voltage are not of as much importance as with incandescent lamps.

Open Carbon Arc Lamps

41. Construction. The open-arc lamp, employing two carbon pencils as electrodes, was the first commercial type of lamp to be used, and was at one time the most efficient form of illuminant. As the name indicates, the arc produced between the electrodes is exposed to the air. Both d.c. and a.c. open-arc lamps have been used, but the d.c. lamp is more common.

42. Applications. The d.c. series, open-arc lamp has been very extensively used in the United States for street lighting and to a limited extent for interior lighting, although in the latter case it is not very satisfactory because of the danger from the high-voltage circuit and also from escaping sparks. The lamp has now been almost entirely replaced by other types of lamps. The d.c., multiple, open-arc lamp has never been extensively used in this country for general illumination. It is, however, used extensively for search lights, stage lighting, and for stereopticons and moving-picture machines. Neither the series nor multiple a.c. open-arc lamp has been used extensively in this country, principally because of the noise and poor distribution of the light. Alternating current is used to a certain extent for hand-feed lamps for projectors where direct current is not available, but the lamps are not as satisfactory as the d.c. lamps. For this reason, especially for moving-picture machines, a converting device is frequently installed to change from alternating to direct current. The disadvantages of open

arcs for general illuminating purposes are unsteady light, strong shadows, frequent trimming, noise and fire hazard.

43. Standard Sizes. The d.c. series, open-arc lamps commonly used for street lighting have the following ratings:

Amperes.	Volts Arc.	Voltage at Terminals.	Candle-power.*	Watts per Candle.*
6.6	48	50	395	0.82
9.6	48	50	690	0.71

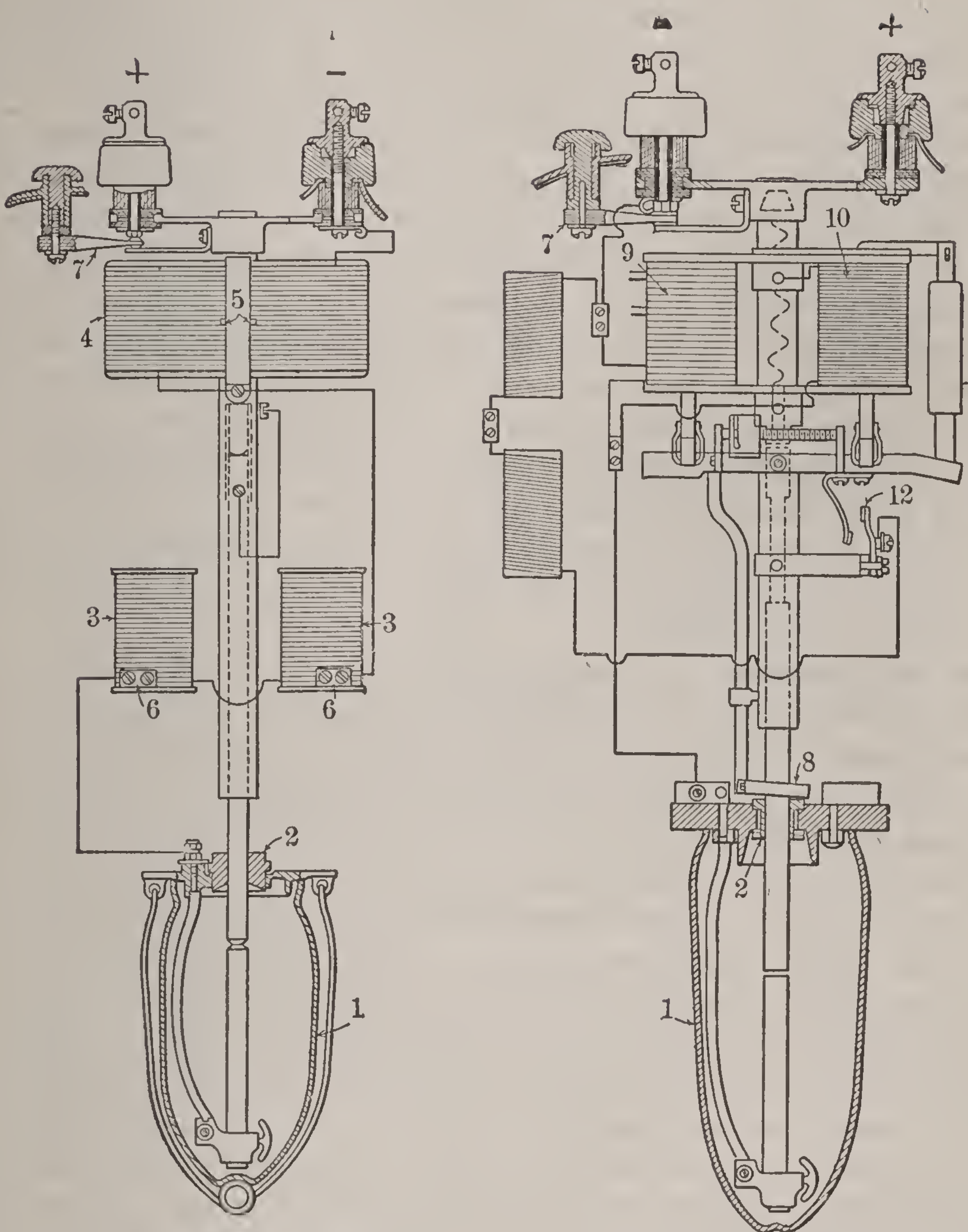
* Mean lower, hemispherical.

The consumption per mean spherical candlepower is about 1.25 watts for the 6.6-ampere lamp and 1.02 for the 9.6-ampere arc. As the life of a 12-in. carbon electrode in these lamps is only from seven to eight hours, usually a lamp is provided with a second pair of electrodes which can be cut into circuit when the first pair has been consumed, thus reducing the amount of attention required.

44. Distribution and Color of Light. The light from the d.c. arc lamp with positive carbon at the top is principally directed below the horizontal. The maximum candlepower of the 6.6-ampere lamp is about 720 at an angle of 45° with the horizontal. For the 9.6-ampere arc the maximum candlepower is 1250 at the same angle. Due to the short arc (about $\frac{1}{8}$ in. long), the lower carbon partially shields the light from the upper carbon and this produces a large dark area directly below the lamp. The a.c. open arc gives a much larger proportion of light above the horizontal and is always used with a reflector. The color of light produced by the open arc is a bluish-white.

Enclosed Carbon Arc Lamps

45. Construction. The enclosed arc lamp differs from the open type in having the arc enclosed in a glass globe, called the inner globe, which is made nearly airtight. This globe is closed at the top by a metal cap or **gas check** (Fig. 4) designed to admit only enough air to consume the carbon vapor formed by the



a. Multiple Lamp. *b*. Series Lamp.

FIG. 4.—D.C. Enclosed Arc Lamps.

1. Inner globe. 2. Gas check. 3. Series coils for operating clutch on upper carbon, adjusting length of arc and thereby keeping current steady. 4. Steadying resistance, adjustable by contact 5. 6. Contacts for changing current taken by lamp. 7. Cutout switch. 8. Clutch. 9. Series coil to regulate arc length. 10. Shunt coil across arc, balancing pull of series coil (9) and keeping voltage across arc constant. 11. Dash-pot for steadying action of magnets. 12. Cut-out.

arc. By this means the life of the electrodes is greatly increased. If the air supply is restricted too much the carbon vapor will deposit on the globe and shut off the light; on the other hand, an excess of air decreases the electrode life. Enclosing the arc, and thereby shielding it from air currents, makes possible a longer arc (about $\frac{3}{8}$ in.), a higher voltage across the arc, and the use of a smaller current. With the open type, the arc voltage is about 48, while with the enclosed arc the voltage is about 72. The electrodes in the d.c. enclosed lamp are pure carbon. For the a.c. lamp, better operation is secured when one of the carbons is cored. **Cored carbons** have a small hole running the entire length and containing certain chemicals which vaporize easily and assist in keeping the arc steady. Fig. 4 gives diagrammatic views of enclosed, d.c. lamps. The arrangement for a.c. lamps is similar. Fig. 4*a* does not show the clutch and dash-pot for this lamp, but they are similar to those shown in Fig. 4*b*.

46. Applications. The **series lamps** are used principally for street lighting and other outdoor applications, because of the hazard when using high-voltage circuits in buildings. The d.c. series lamp is more commonly used than the a.c. lamp because of a better downward distribution of light and the absence of noise. The a.c. lamps are usually operated from 60-cycle circuits. The **multiple lamps** are used for both street-lighting and interior illumination. Their use in street lighting is confined to localities which have low-voltage, constant-potential mains as in the business portions of large cities. These lamps are now being rapidly replaced by gas-filled tungsten lamps, which are frequently mounted in the casing and globe formerly used for the arc lamp. The indoor type of multiple lamp has been widely used for lighting large areas in factories and for store lighting. They are being replaced in more modern installations, however, either by large tungsten units or by flame-arc lamps. The enclosed arc lamps are steadier than the open arcs, but the light is bluer. The efficiency of the enclosed arc lamp is lower than the open arc because of the lower temperature of the electrode tips and the absorption of light by the enclosing globes. The advantages over the open arc are longer electrode life and better light distribution due to the use of a longer arc. The a.c. lamps are noisy and do not give as high efficiency nor as good light distribution as the

d.c. lamps. Besides their use for general illumination purposes, enclosed arc lamps are employed in headlights for locomotives and electric cars.

47. Standard Sizes. Typical performance data for enclosed arc lamps are given in Table 4. This includes the principal sizes now manufactured. A.c. arc lamps are manufactured for operation on 40, 60, and 133 cycles, but 60-cycle lamps are the most commonly used. The 220-volt d.c. multiple lamp is not as efficient nor as satisfactory as the 110-volt lamp because of the longer arc and the smaller current used. It is possible to obtain d.c. multiple-series lamps for use on constant-poten-

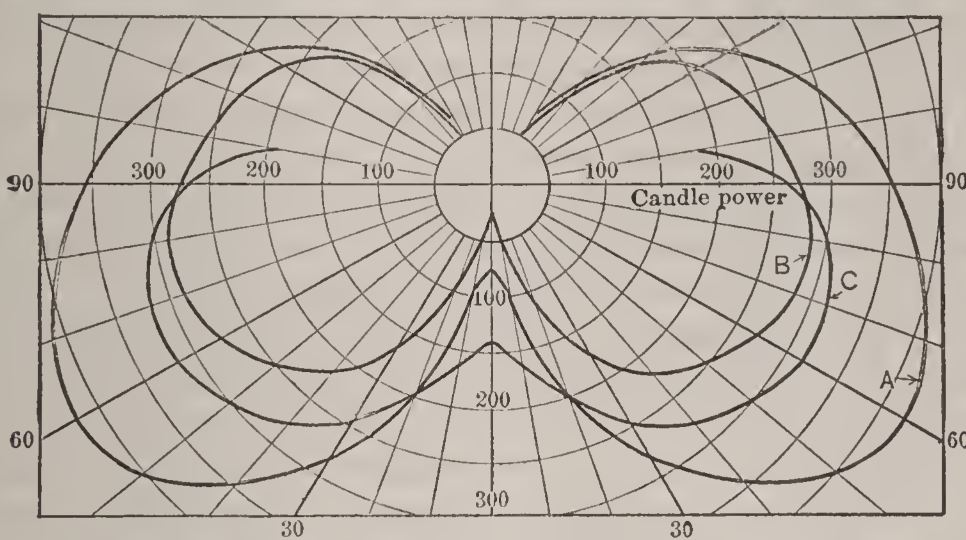


FIG. 5.—Light Distribution of Enclosed Arc Lamps.

Curve *A*, 6-ampere d.c. multiple lamp, no reflector, opal inner globe and clear outer globe. Curve *B*, 7.5-ampere a.c. series lamp, no reflector, opal inner globe and clear outer globe. Curve *C*, same as *B* with porcelain enamel reflector.

tial circuits operating at 220 and above. The lamps are similar to the 110-volt multiple lamp, except the operating mechanism, which inserts a resistance in the circuit when the lamp strikes the arc. This maintains the current at the proper value for the other lamps in series. Each lamp is adjusted to take 110 volts. A.c. lamps are operated on systems having voltages higher than 110 by using a small transformer or compensator to step down the line voltage. Ordinary enclosed arc lamps show a falling off of light during the life of a set of electrodes, due to a deposit which forms on the inner globe. Tests * show that for one hundred hours burning the loss is

* Mathews, Proceedings National Electric Light Assn., 1901, p. 296.

5 per cent for the best grade of carbons and 30 per cent for low-grade carbons.

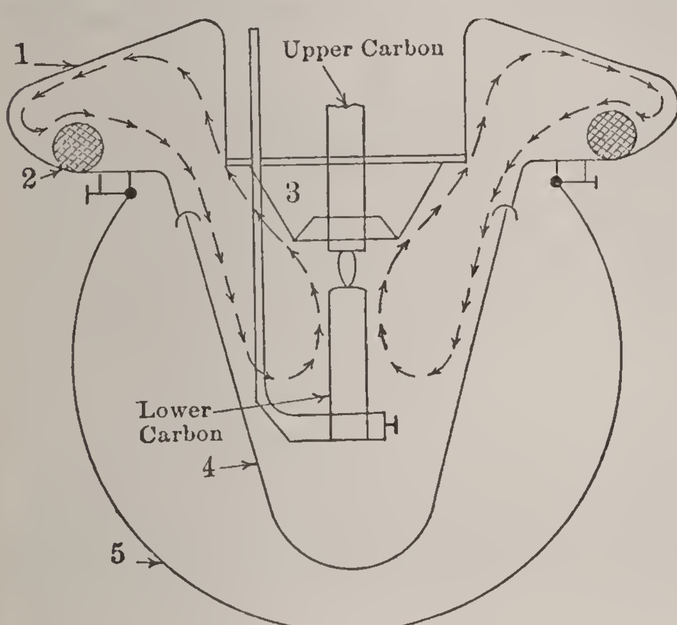
48. Distribution and Color of Light. The distribution of light in various directions is shown in Fig. 5. With the d.c. lamp, without reflector, the largest proportion of the light is directed below the horizontal. The maximum candlepower, about 420 cp. for the lamp illustrated, is produced at an angle of about 30° below the horizontal. With the a.c. arc lamp a large amount of the light is directed above the horizontal. By the use of reflectors, however, the light can be directed in a downward direction. It is customary, in general, to use the lamps without reflectors for outdoor service and to use small reflectors for interior lighting, although the need of reflectors for d.c. lamps is not as great as for the a.c. type. The light from the enclosed arc is bluer in color than the open arc owing to the greater length of the enclosed arc. The light is not very satisfactory for matching colors. By the use of opal enclosing globes, the color of the light is somewhat improved at the expense of lower efficiency.

49. The Intensified Arc. This lamp is a modified form of enclosed arc using small-diameter carbons. Lamps have been developed for d.c. and a.c. multiple circuits, but the d.c. type is most commonly used. The commercial d.c. lamp operates at 110 volts and requires 5 amperes. The lower, negative carbon is $\frac{3}{8}$ in. in diameter and the upper electrode consists of two $\frac{1}{4}$-in. diameter carbons. Because of the small size of the positive carbons, they become intensely hot at the tip, thus giving an increased light and resulting in a higher efficiency. The performance of this lamp is given in Table 4. The light is whiter than the ordinary enclosed arc. The lamp has been used for interior illumination of stores, offices and for similar applications, but is not used to any extent at the present time, since tungsten lamps are more satisfactory.

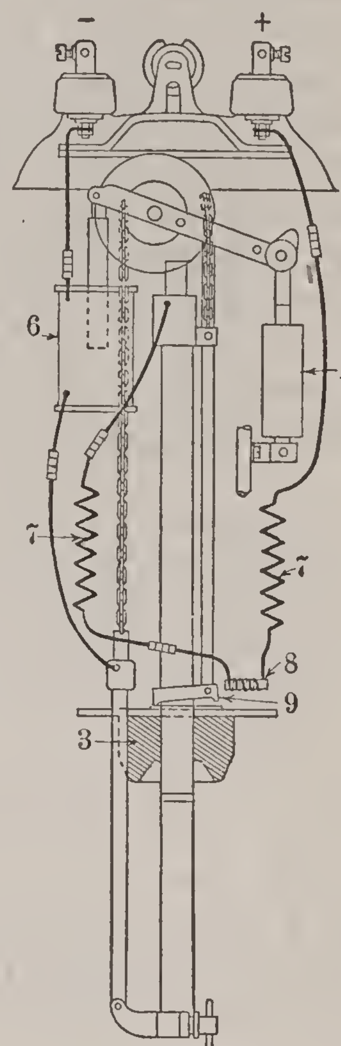
Flame-arc Lamps

50. Construction. Flame-arc lamps employ carbons impregnated with chemicals which render the arc luminous. Most of the light is produced by the arc itself, very little light coming from the electrodes. The lamp is sometimes called the flaming-arc lamp. During the operation of the lamp, a considerable amount of dust is produced and special provision

is made to remove this from the region of the arc, to prevent its accumulation on the globe and the consequent shutting off of the light. The first lamps of this type were open arcs and were not satisfactory, owing to the short life of the carbons (about fifteen hours), the objectionable fumes, and the flickering of the arc. Modern lamps are now made of the enclosed type giving an electrode life of about one hundred hours, and greater steadiness of the light. Fig. 6 illustrates the type of lamp made by one manufacturer. The carbons are enclosed in an inner and an outer globe (Fig. 6*a*). The inner globe con-



a. Lower compartment.



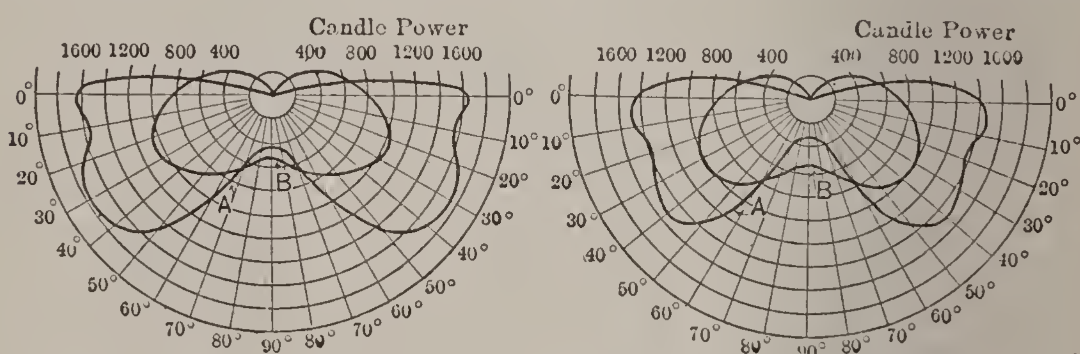
b. Lamp mechanism.

FIG. 6.—D.C. Multiple Flame-arc Lamp.

1. Condenser for removing fumes and dust from arc chamber. 2. Absorbing material for removing glass-etching gases. 3. Economizer for confining arc. 4. Inner globe. 5. Outer globe. Arrows show circulation of air carrying fumes to condensing chamber. 6. Series coil for operating clutch (9) on upper carbon, adjusting the arc and keeping the current steady. 7. Steadying resistance. 8. Blow-coil to keep arc central. 9. Clutch. 10. Dash-pot for steadying the action of the series coil (6).

nects with a "condensing chamber" of metal. The fumes from the arc are carried by air currents into this chamber, and are condensed, since this is cooler than the globe. There are certain gases formed which attack the glass and these are removed by the absorbing material (2) in the condensing

chamber. It has been found that higher efficiency and greater steadiness of light is obtained if the arc is partly confined. The "economizer" (Fig. 6) accomplishes this. It is therefore necessary to keep the arc at a fixed distance below the economizer, and this is done by feeding both carbons instead of the upper one only as is usual with enclosed arc lamps. Fig. 6*b* shows the feeding mechanism and connections for a d.c. multiple lamp. A similar arrangement is employed for the lamps operating on the other kinds of circuits. In order to neutralize the magnetic effect of the current flowing in the rod supporting the lower carbon, a blow-coil (8) is used. This prevents uneven burning of the carbons. The lamps employ a long arc, about 1.75 in. for 110-volt service. Owing to the presence of chemicals in the carbons, there is sometimes difficulty with these lamps due to "slagging" or the formation of glass-like



a. A.C. 7.5-ampere multiple lamp. *b*. D.C. 6.5-ampere multiple lamp.

FIG. 7.—Light Distribution of Flame-arc Lamps without Reflectors.

Curve *A*, lamps equipped with clear outer and inner globes. Curve *B*, lamps equipped with translucent outer and clear inner globes. White-light carbons used. (Westinghouse Elec. & Mfg. Co.)

knobs on the tips of the electrodes. This slag is a non-conductor and sometimes opens the circuit and prevents the lamp from starting. With proper electrodes, however, the slag which forms is easily knocked off by the blow when the electrodes come together.

51. Applications. The flame-arc lamps are especially adapted for the illumination of large areas, where the lamp can be mounted at a considerable height. Because of their high candle-power, they should never be used for small rooms or where they are in the direct line of vision. They are specially suited for lighting smoky or dusty places such as foundries, blacksmith shops, and railway yards, and have been used extensively for

street lighting. The lamps are used on both direct and alternating current and for series and multiple circuits. A.c. lamps are usually operated on 60-cycle circuits, but they are also made for 25 cycles. The gas-filled tungsten lamp is a serious competitor of the flame-arc lamp and the tendency is at present to use the tungsten lamp for many places where a few years ago the flame-arc would have been employed.

52. Standard Sizes. The commercial sizes of enclosed or long-burning flame-arc lamps vary somewhat with different manufacturers. Table 5 gives data for the common sizes. By providing small transformers or compensators, the series a.c. lamp may be operated on circuits having different values of current. The a.c. multiple lamp is adapted for 220-volt circuits by using a small transformer mounted inside the lamp. Lamps for 25 cycles cost somewhat more than 60-cycle lamps. The electrodes are usually 14 in. long and $\frac{7}{8}$ in. in diameter. For enclosed flame-arc lamps, the decrease in the lower mean horizontal candlepower during 100 hours' burning is about 20 per cent.

53. Distribution and Color of Light. The distribution of light from the flame-arc without reflector depends upon the kind of enclosing globe used. With clear outer and inner globes such as would be used out doors, the maximum candlepower for the d.c. (10-ampere) lamp is about 1900 at an angle of 11° below the horizontal. For the a.c. (10-ampere) lamp, with clear globes and no reflector, the maximum candlepower is about 1700 at 8° below the horizontal. The distribution of light for d.c. and a.c. lamps is shown in Fig. 7. It will be noted that the maximum candlepower is at practically the same angle (about 30° below horizontal) for both d.c. and a.c. lamps. The use of opal diffusing globes is generally necessary for interior illumination, although the efficiency is thereby reduced about 20 per cent. For industrial purposes, reflec-

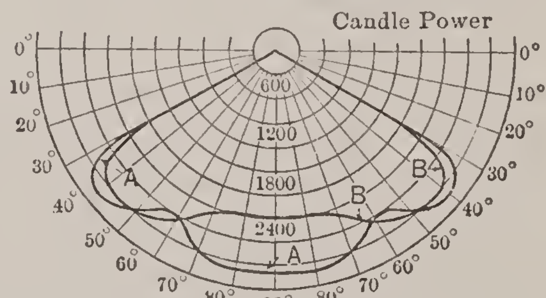


FIG. 8.—Light Distribution of Flame-arc Lamps with Industrial Reflectors.

Curve *A*, A.C. 7.5-ampere multiple lamp, clear inner globe. Curve *B*, D.C. 6.5-ampere multiple lamp, clear inner globe. White-light carbons used. (Westinghouse Electric & Mfg. Co.)

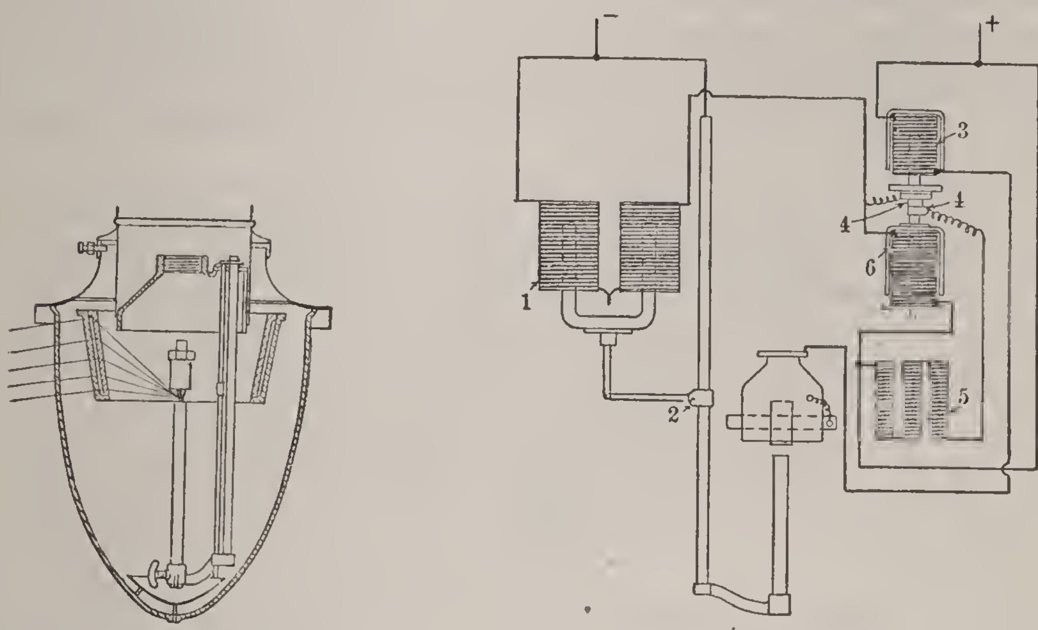
tors are sometimes employed to concentrate the light. These reflectors produce a distribution about as shown in Fig. 8. The light produced by the flame-arc may be made either white or yellow, depending upon the kind of electrodes used. The curves already discussed were made from lamps using white-light carbons. Yellow-light carbons give about 25 per cent more light. White-light carbons are usually employed for street lighting and interior illumination. For railway yards and smoky or dusty places, the yellow-light carbons are preferred.

Metallic-electrode Arc Lamps

54. Construction. This type of lamp is sometimes called the magnetite lamp, because one of the electrodes is composed of an ore of iron called magnetite. The lamps are in many respects different from either the enclosed arc or the flame-arc. No carbon is used in the electrodes of the lamp and the light comes almost entirely from the arc itself. The lamp is used only on direct current. The positive electrode is a composite block of copper and iron, the form varying with the different manufacturers. The negative electrode is composed of a mixture of powdered iron oxide or magnetite and several light-producing oxides, all moulded into the form of a rod. The material is a non-conductor when cold, so the rod is either enclosed in an iron tube or has an iron wire moulded into the center to carry the current. The positive electrode is not consumed rapidly and has a life of several thousand hours for one type of lamp. For another make, this terminal is smaller and is replaced at each trimming of the lamp. In the Westinghouse lamps, the positive terminal is at the bottom, while in the General Electric lamp, this terminal is at the top. Each company claims advantages for the arrangement adopted. Because of the fumes and soot produced by the lamp, special arrangements are made to ventilate the arc space and carry these fumes out of the lamp. The arc is enclosed in a single large globe, generally of clear glass. Fig. 9 shows the arrangement used by one manufacturer. The feeding system is similar to that used in the enclosed arc lamp.

55. Applications. The lamp is principally used on series or constant-current circuits for street lighting and is now the standard lamp for this purpose. It is much more extensively

used for this work than either the flame-arc or the high candle-power tungsten units, although the latter are rapidly gaining in favor. The metallic-electrode arc is also used in head-lights for interurban cars. The lamp is also made for d.c. **multiple** circuits and is used for the illumination of parks, mills, foundries, machine shops, train-sheds, freight yards and similar places. The lamps arranged for pendant burning, as shown in Fig. 9, are commonly used for street lighting.



a. Sectional view showing refractor. *b.* Connections.

FIG. 9.—Series Metallic-electrode Arc Lamp.

When lamp is not in service electrodes are separated. When lamp is connected to circuit, current flows from + through starting resistance (5), contacts (4) and starting magnet (1). This raises the lower electrode by means of clutch (2) and contact is made with upper electrode. Current then flows through series magnet (3), which opens contacts (4), thus separating electrodes and striking arc. The shunt magnet (6) is now energized through the starting circuit. If the arc becomes too long the voltage rises, the shunt magnet closes contacts (4) and the electrodes are brought together again, the clutch taking a different position on the electrode rod.

An **ornamental type** of lamp is also made for mounting at the top of an ornamental post or standard. These lamps have the mechanism below the arc and are enclosed in a translucent diffusing globe. Metallic-electrode lamps are not well adapted for general use indoors because of the copious fumes given off.

56. Standard Sizes. The commercial lamps are also known as "metallic-flame" or "luminous-arc" lamps. The sizes made by the various manufacturers vary slightly in rating. Table 6 gives performance data for the lamps made by one

manufacturer. For 220- and 550-volt, constant-potential circuits, 110-volt multiple-series lamps are used. The loss of light during the life of one electrode is relatively small because of the thorough ventilation of the lamp.

57. Distribution and Color of Light. The lamp gives the maximum candlepower at an angle slightly below the horizontal, and it is therefore well adapted for street lighting where most of the light must be directed to points a considerable distance from the lamp. The angle for the maximum candlepower varies somewhat with different makes of lamps and with different sizes, but all types give high candlepower values for angles between 10° and 45° below the horizontal. Fig. 10

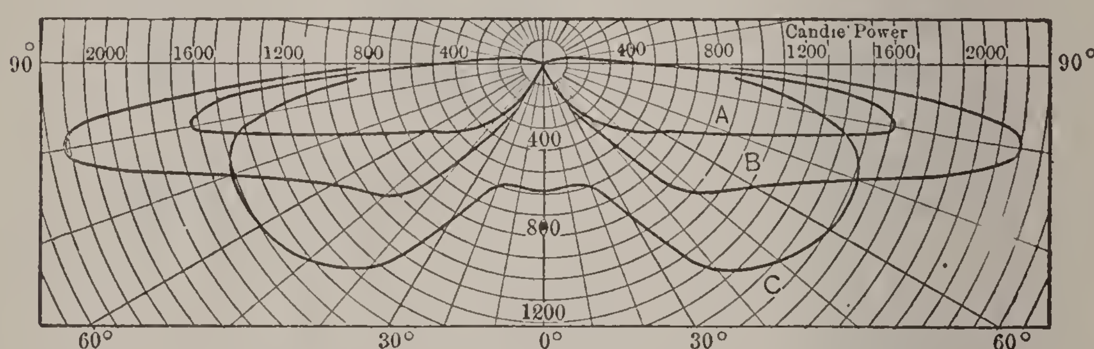


Fig. 10.—Light Distribution of Metallic-electrode Arc Lamps.

Curve *A*, 4-ampere luminous arc lamp, with refractor and high-efficiency electrode. Curve *B*, 5-ampere luminous arc lamp, with refractor and high-efficiency electrode. Curve *C*, 6.6-ampere luminous arc lamp, with reflector and standard electrode. (General Electric Co.)

shows the distribution of light at various angles above and below the horizontal for the pendant type of lamp used for street lighting. Two kinds of lamps are made, one having an internal reflector, and the other a glass refractor (Fig. 9*a*). Each of these devices is designed to direct most of the light at an angle slightly below the horizontal (about 10°), as this gives the best distribution for street-lighting purposes. The light produced by the metallic-electrode arc is white in color and closely resembles daylight. It is therefore very well suited for street lighting.

Mercury-vapor Lamps

58. Construction. Mercury-vapor lamps are of two kinds: the low-pressure, glass-tube type, and the quartz-tube type.

The light-producing element in these lamps is an arc of mercury vapor confined in a tube of glass or quartz. All of the light is produced by the arc and none comes from the electrodes. The amount of light given off depends greatly upon the pressure in the tube, and this, in turn, is fixed by the temperature. The **low-pressure type** uses a glass tube and operates at a very low pressure. The temperature of the arc is therefore low (about 200° Cent., or 392° Fahr.). The tube is operated in a slightly inclined position. Mercury is used as the lower elec-

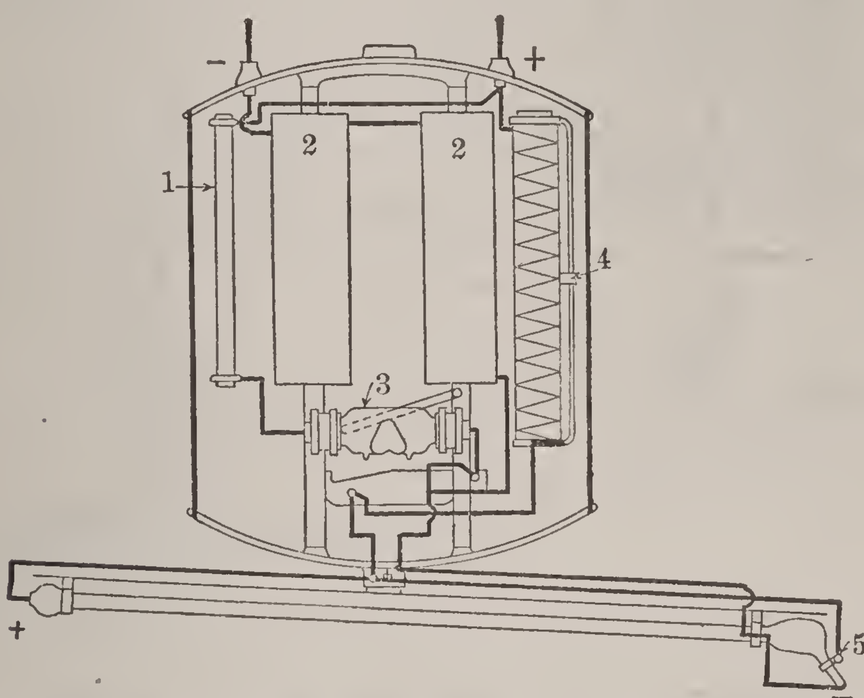


FIG. 11.—Diagram of 110-volt Direct Current Cooper Hewitt Lamp. (Low-pressure type).

1. Starting resistance. 2. Inductance coil. 3. Shifter. 4. Adjuster resistance. 5. Starting band.

trode, which is connected to the negative terminal of the circuit. The other end of the tube is enlarged and contains the positive terminal, which is made of iron or graphite. The mercury forming the negative terminal is vaporized by the action of the current and is condensed in the enlarged part of the tube at the top. From this "condensing chamber" it runs back to the lower terminal, so as to maintain the supply of mercury. The tube for a 110-volt lamp is about 50 in. long and 1 in. in diameter. When the lamp is not operating, a vacuum exists in the tube and there is consequently a high resistance between the terminals. The lamp may be started by tilting the tube

until a thin stream of mercury connects the two terminals. When the tube is tilted back again this stream is broken, an arc is formed and a conducting path of mercury vapor results. The tilting may be accomplished either automatically or by hand. The arc may also be started by breaking down the resistance between the terminals with a spark coil. The mercury arc will not operate unless supplied with direct current. For a.c. lamps, it is therefore necessary to provide some method of keeping the lower terminal negative. By means of an additional terminal near the upper end of the tube, the alternating

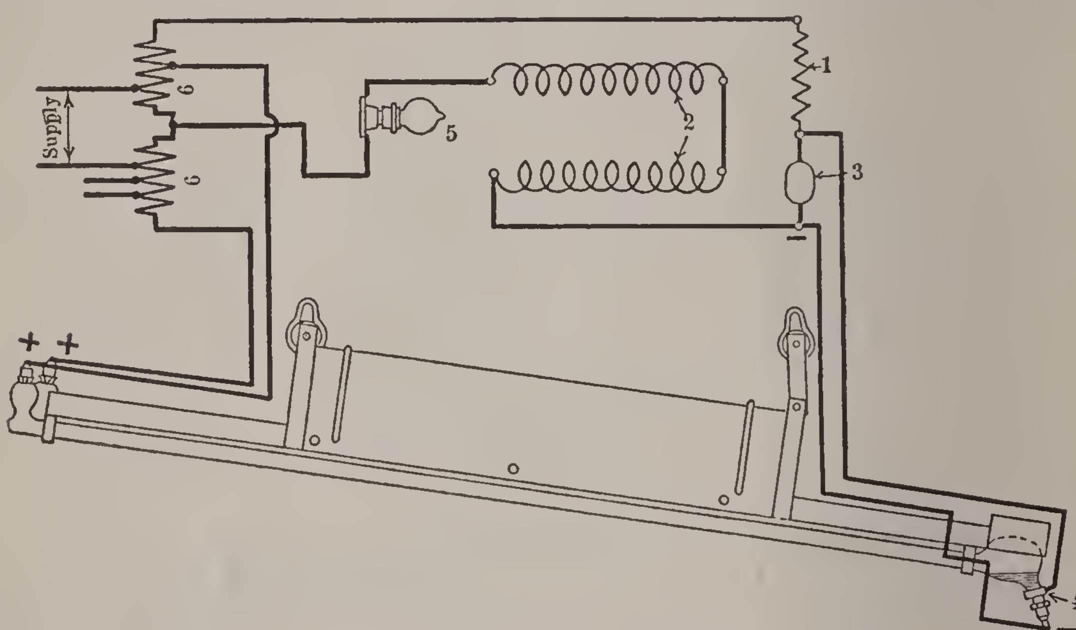


Fig. 12.—Diagram of Alternating Current Cooper Hewitt Lamp. (Low-pressure type.)

1. Starting resistance. 2. Inductance coil. 3. Shifter. 4. Starting band. 5. Series resistance (ballast) to steady arc. 6. Auto transformer.

current is changed to direct current or "rectified" and the proper current supply for the arc is maintained. Fig. 11 shows the arrangement and connections for the 110-volt low-pressure, **d.c. lamp** arranged for automatic starting. The tube requires a resistance in series to keep the current at a steady value, and also requires inductance coils in series to prevent the arc from being extinguished at irregular intervals. The "shifter" breaks a circuit through the inductance coil, thereby applying a high voltage on the "starting band" and causing the lamp to light. The d.c. lamp is also made to start automatically by tilting, the mechanism used for this purpose being similar to that shown in Fig. 13. Fig. 12 shows a diagram of

connections of the **a.c. lamp**. This lamp requires a steadying resistance, or ballast, and an inductance coil. A shifter and starting resistance to limit the current are also provided. Referring to Fig. 12 it will be seen that the line is connected across the terminals of an auto-transformer and the negative terminal of the lamp is connected to the centre of this transformer. The two sides of the transformer are connected to the two positive terminals of the tube. By this means the tube is always kept at the proper polarity and direct current flows through the tube and inductance coil. The **quartz-tube lamp** differs from the ordinary type of lamp in having a very short tube, about 4 in. for a 220-volt lamp. This results in a very much higher pressure and temperature of the arc, with a corresponding difference in the character of the light produced. The quartz lamp operates with about atmospheric pressure in the tube and the temperature of the arc becomes so high that ordinary glass would soften. For this reason, the tube is made from fused quartz. Fig. 13 shows the arrangement and connections for a 220-volt quartz lamp. The lamps are arranged for automatic starting by tilting the burner and require a series resistance (8) and an inductance coil (5), the same as the low-pressure lamps. This resistance may be adjusted (6) to suit the supply voltage. When current is supplied to the lamp, a circuit is formed through the magnet coil (2), starting resistance (7), cutout (4) and adjuster resistance (6). The magnet then pulls up the armature (3) and tilts the tube, thus forming a circuit through

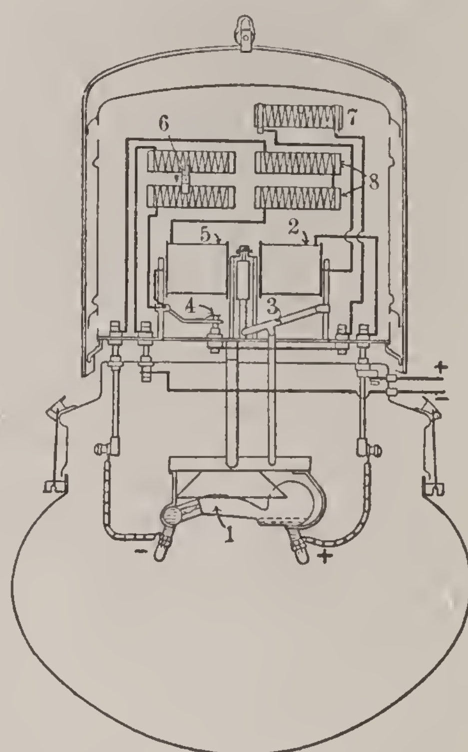


FIG. 13.—Diagram of 220-volt Cooper Hewitt Quartz Lamp.

1. Quartz burner. 2. Magnet coil for tilting burner. 3. Armature operated by (2). 4. Cutout operated by (5), open when lamp is burning. 5. Inductance coil for maintaining the arc. 6. Adjuster resistance for setting lamp for different supply voltages. 7. Starting resistance to limit current when arc is formed. 8. Series resistance to steady the arc.

the tube, series resistance (8), inductance coil (5) and adjuster resistance (6). When current flows in the circuit, the inductance coil opens the cutout (4), which breaks the circuit through the magnet coil, restoring the burner to a level position, thereby breaking the mercury path in the burner and starting an arc.

59. Applications. Mercury-vapor lamps have been used principally for industrial illumination because of the peculiar color of the light. They are particularly adapted for lighting metal and wood-working plants, textile mills, printing establishments, warehouses and yards. They are also very well adapted for photographic work because the light given off is more active photographically than other artificial illuminants. The lamps are used extensively for portrait and moving-picture studios, and for photo-engraving. Lamps are used on both a.c. and d.c., constant-potential circuits. The lamps have been found to be especially adapted for illuminating work requiring close attention to details.

60. Standard Sizes. The commercial styles are called Cooper Hewitt Lamps. Table 7 gives data on the usual sizes manufactured. For indoor use, the **low-pressure lamps** are provided with a spark coil for starting, as explained in paragraph 58. For outdoor service and for interior use, where the temperatures are likely to be low, the spark coil type of lamp does not start readily, and the tilting type of lamp (either automatic or hand) must be used. For d.c. circuits above 110 volts, the tubes are burned in series. For a.c. circuits, a small transformer is used to step down the voltage to 110. The a.c. lamps may be operated on 50 or 60 cycles. They are started in the same way as the d.c. lamps. The **quartz-tube lamp** is at present made for d.c., 220-volt, multiple circuits. Where these lamps must be operated from a.c. circuits, a specially designed mercury-arc rectifier is provided to operate a group of lamps. The power consumption of the low-pressure lamp is about 0.48 watt per m.h.cp. for both the d.c. and the a.c. lamps. The quartz lamp has a higher efficiency, about 0.30 watt per m.h.cp. The life of the tubes is very long, generally several thousand hours. The candlepower decreases, however, with burning. For the low-pressure type, tests show that the candlepower falls to about 80 per cent of the rated value after 2000 hours burning. When the low-pressure lamp is started,

the current is momentarily about double the normal value until the arc has been established. With the quartz lamp, starting cold, the current rush is about four times normal, but this drops rapidly as the tube heats up. At the end of three minutes, the current is about 50 per cent above the normal value, which is reached in from fifteen to twenty minutes.

61. Distribution and Color of Light. Since the light is given off equally in all directions at right angles to the axis of the tube, the lamps must always be used with reflectors. These take the form of U-shaped metal troughs which enclose the tube on one side. Usually these reflectors have a white porcelain surface. The reflectors are so designed that all the light is directed below the horizontal, the maximum candlepower being vertically downward. The light produced by the low-pressure lamps has a pronounced bluish-green color, with practically no red rays. For this reason, it is not at all adapted for use where color values are important or where artistic illumination is desired. It is, however, very satisfactory for industrial work. The light from the quartz lamp contains more red rays, but it is still decidedly greenish in color. The improvement is due to the higher temperature of the arc. The quality of the light cannot be improved by the use of colored enclosing globes, since these could not *add* any red rays. By using flame-arc lamps or tungsten lamps combined with mercury-vapor lamps in the proper proportion, the resulting illumination may be greatly improved and made more nearly like daylight. The low-pressure lamps are sometimes provided with reflectors coated with rhodamine enamel, which gives off red rays when the lamp is operating. This considerably improves the quality of the light produced. These reflectors are called "light transformers" or "red reflectors." The quartz lamp when operating without the enclosing globe is very injurious to the eyes, because of certain invisible "ultra-violet" rays.* The ordinary clear glass globe cuts off these rays and renders the light safe.

62. Other Vacuum-tube Lamps. The **Moore-tube** lamp has been used to a limited extent for commercial lighting. It consists of a glass tube varying in length from 60 to 200 ft. and containing a gas at low pressure. A high voltage is applied to terminals at each end of the tube, thereby causing the gas

* See paragraph 65.

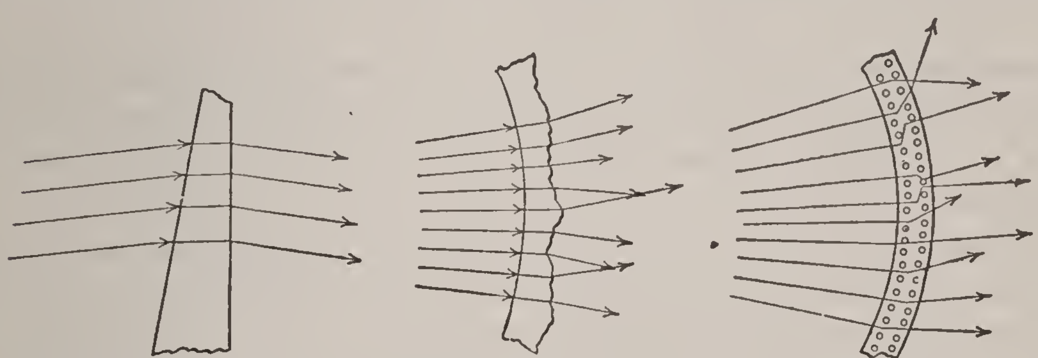
to become luminous. The color of the light produced depends upon the kind of gas used. With nitrogen gas the light is yellow, and with carbon-dioxide gas it closely resembles daylight. The tubes have a power consumption of about 2.5 watts per m.s.cp. when nitrogen is used. This type of vacuum tube is no longer used in long lengths for general illumination, but a special outfit has been developed to give daylight effects for show windows and color matching. The **neon-tube** has been developed in France. This is similar to the Moore-tube, the gas used being neon, which is found in very small quantities in the atmosphere. Tubes filled with this gas require only about one-third the voltage necessary for the Moore-tube, and the candlepower per foot of tube is three times as great. The light is a golden orange color. Due to the difficulties encountered in extracting the neon from the air, the tubes have not come into extensive use. In France, they have been made in various shapes and sizes, for general illuminating purposes, and with the tubes shaped in the form of letters for use in advertising. The power consumption is stated to be about one-third that for the Moore-tube.

CHAPTER 4

PRINCIPLES OF ILLUMINATION

63. Light. When a body is heated, it finally reaches a temperature where it begins to give off light which is red in color. As the temperature is increased the color changes, first to yellow and finally to white, and the light efficiency increases rapidly. A high temperature is therefore necessary in an incandescent lamp. White light is composed of light of three **primary colors**, red, green, and blue, combined in the proper proportion. If these proportions are changed the light will no longer be white, but will have a color which will depend upon the relative amount of each primary color present.

64. Reflection and Color. Light rays travel in straight lines unless interfered with by some medium which absorbs or deflects



a. Regular refraction. *b.* Irregular refraction. *c.* Diffusion.

FIG. 14.—Examples of Refraction.

them from their original course. **Refraction** occurs when the light is deflected slightly from the straight path, in passing obliquely through transparent materials like glass or water. Fig. 14 gives examples of refraction. **Regular refraction** (*a*) occurs when the light passes through wedge-shaped pieces of glass such as the ribs of the prismatic type of reflectors. **Irregular refraction** (*b*) occurs when the glass surface is rough, as in frosted globes. **Diffusion** (*c*) occurs when there are par-

ticles in the glass which reflect the rays in various directions. Globes made of white or translucent glass give this effect. **Reflection** occurs when the light strikes an opaque object and is given off again in a different direction. Reflection may also occur with transparent objects if the light strikes the surface obliquely. Fig. 15 illustrates different kinds of reflection. **Regular reflection** (*a*) occurs when the light strikes highly polished surfaces, such as silvered mirrors and polished metal or wood-work. With **irregular reflection** (*b*) the reflected light rays do not all leave the surface at the same angle, but are directed at different angles. This type of reflection occurs with aluminum-finished reflectors and etched-glass surfaces. **Subsurface reflection** (*c*) occurs when the light passes through

a. Regular reflection. *b.* Irregular reflection. *c.* Sub-surface reflection.

FIG. 15.—Examples of Reflection.

a transparent portion of a surface and is reflected at various angles by opaque particles located beneath the surface. This type of reflection occurs with porcelain enameled and painted surfaces.

A portion of the light which strikes an opaque object is always absorbed, the amount depending upon the character of the object. Substances of different kinds do not reflect light in the same way, and from this result differences in appearance and in color. A **black** body reflects no light, and hence it can be seen only by contrast with nearby objects which reflect light. A body illuminated by white light will appear white provided it reflects the primary colors of which white light is composed, in such an amount as to maintain the proper proportion of each. On the other hand, if it reflects more light of one color than another, the object will not appear white even when illuminated by white light. A body which appears red reflects the red light and absorbs the other colors. It should be noted, however, that if an object appears of a certain color, the light which is used to illuminate the object must also contain that color. For this reason, the mercury-vapor lamp, which produces

no red rays, gives very peculiar effects. Objects which would appear red, when illuminated by white light, appear black under the mercury-vapor lamp, since no light rays are reflected. Any color which is composed partly of red would not appear in its true color, and objects normally white have a greenish-blue color when illuminated by the mercury-vapor lamp. The color of the light in a room is not always the same as the color of the source. If white light is produced in a room with green walls, most of the light which strikes the walls is absorbed, while the green rays are reflected, thus giving a green tint to the illumination. Dark walls and ceilings result in a low efficiency of the lighting system, since much of the light produced is absorbed and lost.

65. Quality of Light. The light produced by an artificial source is usually compared with daylight, which is commonly called white light. Artificial illuminants in general do not exactly reproduce daylight effects, but by means of special screens some of the more efficient lamps can be made to closely approximate white light. Incandescent lamps are in general somewhat yellow, while some arc lamps give a bluish light. Light vibrations, at rates slightly higher than those which are visible, produce "ultra-violet rays," more correctly called ultra-violet radiation. These are produced by most light sources, but usually in so small an amount as not to be injurious to the eyes. The electric arc and the quartz-tube lamp, however, produce a large amount of these radiations and are therefore dangerous to the eyes, unless shielded by ordinary glass, which largely cuts off the ultra-violet rays while still allowing the visible rays to pass freely.

66. Units.* The **candlepower** or intensity of light emitted by a lamp in a given direction is expressed in terms of a standard source of light. Formerly this was a special form of candle, burning under specified conditions. The present unit, the **international candle**, is however based upon certain standard incandescent lamps maintained by the Bureau of Standards at Washington. Thus a lamp which gives, in a specified direction, a light intensity twenty times as great as the standard

* The term "unit" as used in this paragraph refers to its usual meaning of a standard of measurement. The term "light-unit" sometimes abbreviated unit, is commonly used in lighting work and will be explained in a later paragraph.

candle would be said to give 20 cp. in that direction. Artificial illuminants do not, however, give the same candlepower in all directions; thus a 100-watt tungsten lamp which may give 96 cp. in a horizontal direction will give only about 30 cp. vertically downward (see Fig. 20). It is unfair, therefore, to compare different kinds of lamps upon the basis of the candlepower in one direction only. A more accurate comparison may be made when the *average* candlepower is employed. This average may be taken in several ways. We may, for example, measure the candlepower of an incandescent lamp in a large number of directions all of which are in a horizontal plane

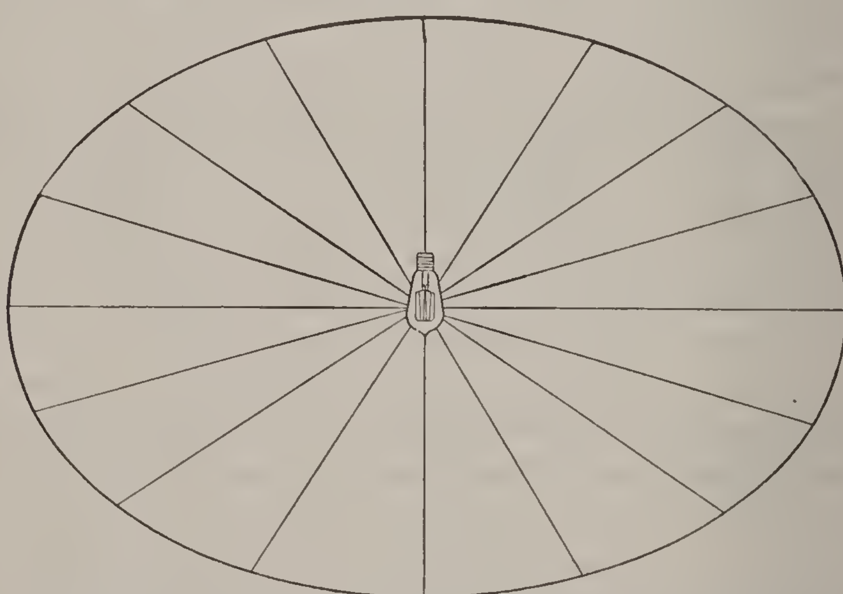


FIG. 16.—Measurement of Mean Horizontal Candlepower.

through the center of the lamp. Fig. 16 illustrates the arrangement, the radial lines equally spaced representing the various directions in which the candlepower is to be measured. The *average* of the candlepower values so obtained gives the **mean horizontal candlepower** (abbreviated m.h.cp.) of the lamp. In actual practice, this value would be obtained, not by making a large number of readings, but by rotating the lamp, thereby measuring directly the average candlepower. Until recently, incandescent lamps were rated commercially on the basis of their mean horizontal candlepower. It is sometimes desired to express the candlepower of a lamp in other directions than the horizontal. We can imagine the lamp located at the centre of a globe or sphere. If we should measure the candlepower of

the lamp at a large number of points equally spaced on the inside surface of this sphere, we would find a wide variation in the candlepower of the lamp. If we average all of these readings we obtain the **mean spherical candlepower** (abbreviated m.s.cp.) of the lamp. In this way, we take account of *all* the light produced, and comparisons between different lamps can therefore be made more accurately than by other methods. For this reason, commercial ratings of lamps are now commonly expressed in terms of the mean spherical candlepower. If we consider only the lower half of the sphere, the averaged readings would give the **mean lower hemispherical candlepower** (abbreviated m.l.h. cp.). This term has been used commonly in the commercial rating of arc lamps. The candlepower of a lamp is a measure of the brightness or intensity of the light in a given direction, and this candlepower would remain the same irrespective of the distance between the lamp and the point of measurement. Thus, if a tungsten lamp was found to give 100 cp. when measured in a certain direction at a distance of 10 ft., another measurement made at a distance of 100 ft. *in the same direction* would be found to give the same *candlepower.* This would hold true for all distances in a given direction, except when the distance becomes so great that some of the light is absorbed by the atmosphere. The *illumination,* however, decreases rapidly with increase in distance, as will be explained later. The **output of light** from a lamp is called the **light flux** and is measured in **lumens.** We can compare a lamp with a metal ball supplied with water under pressure. If a large number of small holes, equally spaced, are drilled in the ball, then neglecting the effect of the supply pipe, jets of water would issue from the ball in all directions. These jets may be compared with the light flux given off by a lamp. The total amount of water issuing from the ball would be the aggregate from all the holes and would correspond to the total light which would be given off by the lamp. This would be expressed in lumens. We may speak of the total lumens or total light flux produced by a lamp which includes the light given off in *all* directions, or we may consider only a particular portion of the light given off, as for example, the lumens in the lower hemisphere. We may also use the term **lumens per watt,** which is found by dividing the total lumens output by the watts required to produce this output. This quantity is convenient

for comparing the efficiency of two lamps. For example, a 500-watt tungsten lamp gives 8050 lumens, or 16.1 lumens per watt. A certain arc lamp requires 495 watts and has an output of 3650 lumens, or 7.37 lumens per watt. We can therefore say that the tungsten lamp is twice as efficient as the particular arc lamp considered. In calculating values of lumens per watt, it is customary to use the *total* watts supplied to the lamp so as to include the losses in the lamp mechanism. Referring to the two lamps just compared, it should be remembered that the *candlepower* of the tungsten lamp in certain directions would not be twice as great as the arc lamp. In fact the candlepower of the arc lamp at an angle of 30° below the horizontal is 530, while the tungsten lamp at the same angle gives about 700 cp. The *candlepower* may be changed by the use of reflectors,* but the *total light output in lumens is the same* whether a reflector is used or not, provided the power consumed by the lamp remains the same. The lumens given off in a *definite direction*, for example downward, may be changed materially if a reflector is used; in other words, the flux, which originally was directed upward, might now all be directed downward, except for the amount absorbed by the reflector. In fact, a reflector may be thought of as a sort of nozzle which serves to turn the light into a useful direction. Fig. 17 illustrates the effect of reflectors upon the light distribution. For purposes of comparison, it is also necessary to determine the amount of illumination produced at a given point by the light source. This is expressed by the term **foot-candles** † or lumens per square foot. Thus, if the flux of light on a given surface is such that there are 4 lumens per square foot, then we would say that the illumination produced was 4 foot-candles. It is necessary to distinguish carefully between the *candlepower* of a lamp and the *quantity of light* which reaches a particular object. The candlepower of a lamp in a certain

* See paragraph 79.

† By definition, a foot-candle is the illumination produced on a surface situated 1 ft. distant from a light source of 1 cp. The foot-candle illumination of a surface can be obtained in any case by dividing the candle power of the lamp in the direction considered by the square of the distance in feet from the lamp to the given surface. One foot-candle is about equal to the illumination produced on a surface situated 5 ft. horizontally from a 25-watt tungsten lamp without reflector. This unit is now being replaced by the term *lumens per square foot.*

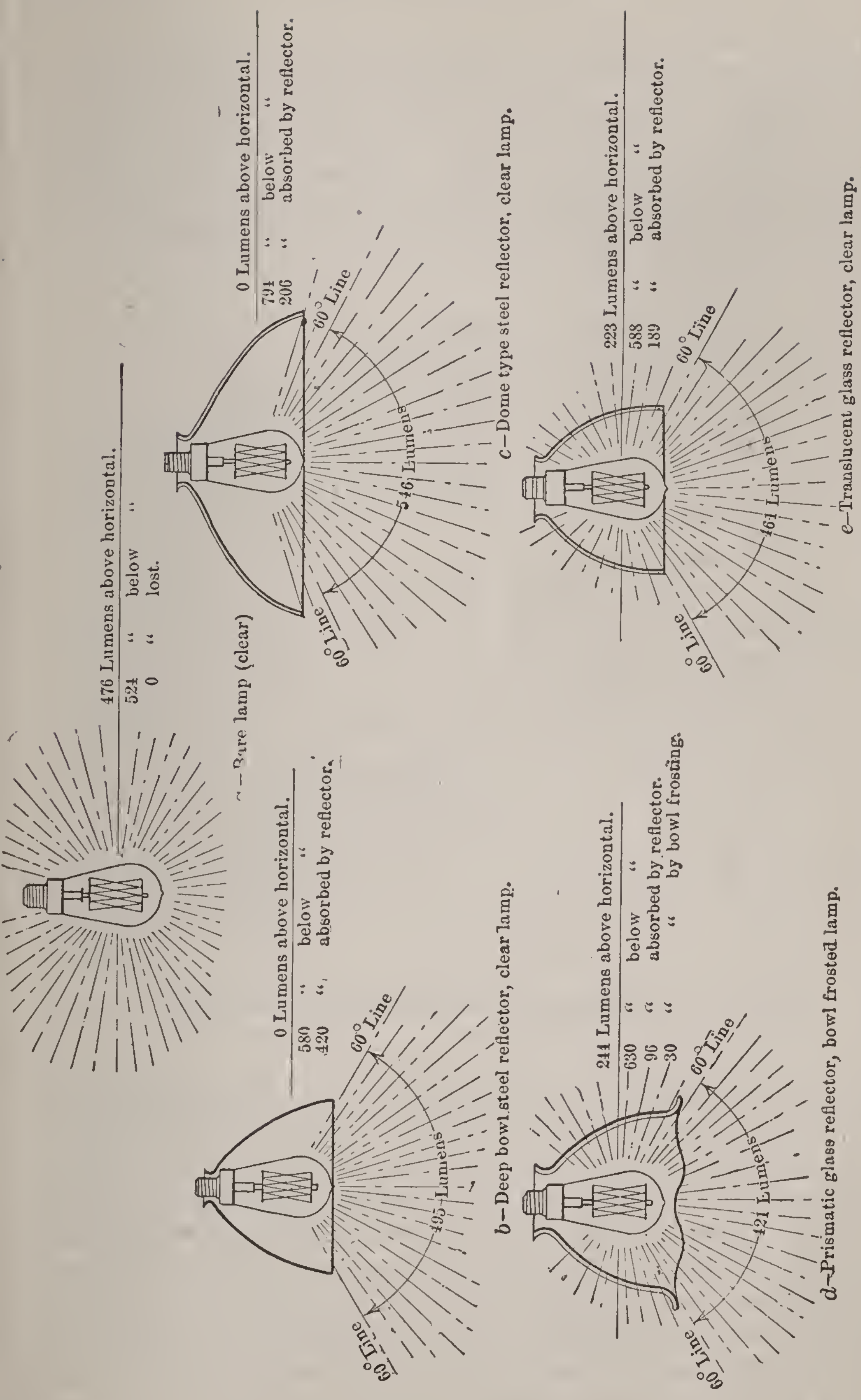


Fig. 17.—Effect of Reflectors upon Distribution of Light.
Based on a 100-watt tungsten lamp producing 1000 lumens total light flux.

direction is definite and would be the same if measured close to the lamp or at a distance of hundreds of feet, as has already been explained. The quantity of light which falls on a given area, however, that is, the lumens per square foot, depends upon the distance from the lamp. Suppose a surface (*a*, Fig. 18) is placed at right angles with the light from a lamp and distant 5 ft. from it; the light, which we will consider con-

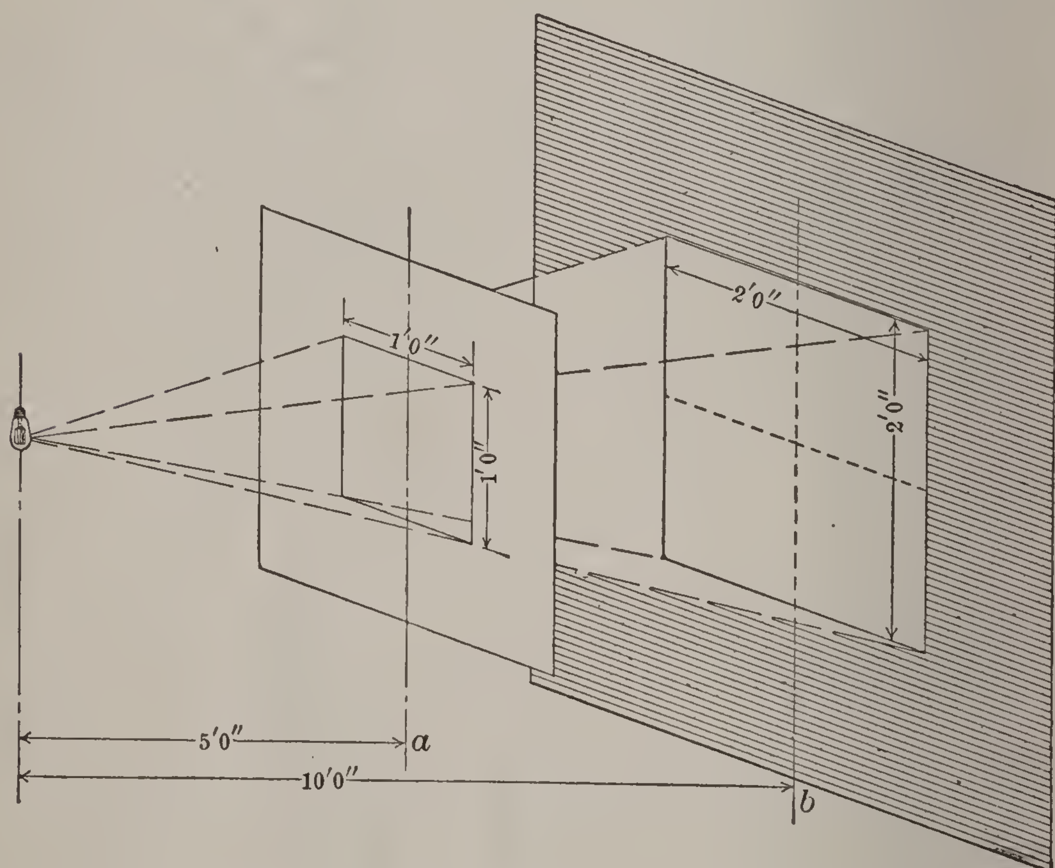


FIG. 18.—Variation of Illumination with Distance.

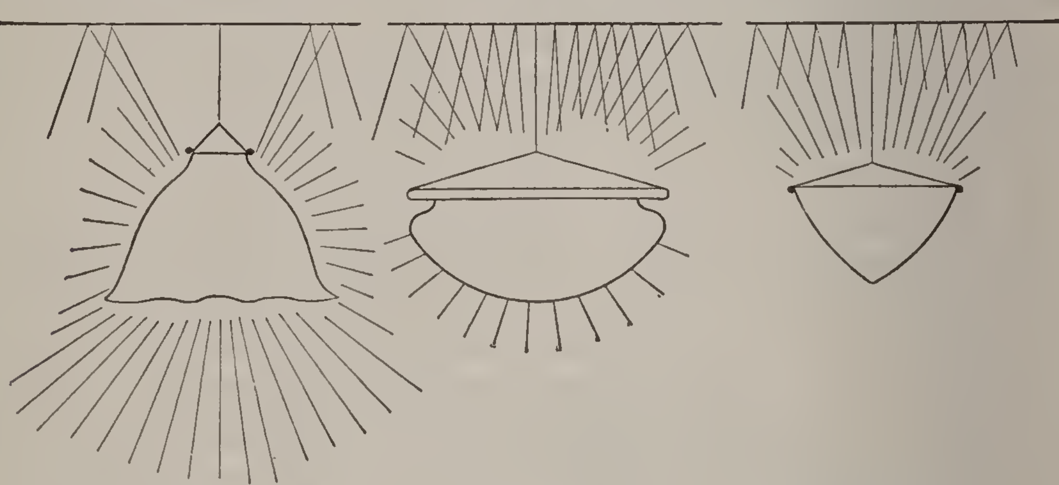
centrated at a point, would illuminate the surface practically uniformly. Suppose this illumination amounts to 16 lumens per square foot of surface, in other words 16 foot-candles. If we now cut an opening of 1 sq.ft. area in this surface, we shall allow 16 lumens of light flux to pass through and strike the surface (*b*), which is at twice the distance from the light. Since the light travels in straight lines, it will spread over more than 1 sq.ft. of the surface of (*b*). In fact, it will be seen that the surface illuminated will measure 2 ft. on a side, giving a total area of 4 sq.ft. Hence the light flux, amounting to 16 lumens

is now spread over *four* times the surface and the illumination will be one-fourth as great, or 4 lumens per square foot (4 foot-candles). This law is expressed by saying that the illumination of a surface varies inversely as the square of the distance from the light source. While this **inverse square law** is exactly true only when the light is concentrated at a point and the surfaces are spherical, it is very closely correct for ordinary lamps and flat surfaces at considerable distances from the light. There are many cases in actual practice, however, where the law should be used with care because of the changes occasioned by the use of reflectors.* If the light does not strike the surface at right angles, the illumination for a given amount of light is less, since it is spread over a larger area. The total lumens produced by a lamp can be found by multiplying the mean spherical candlepower by 12.57.

67. Distribution Curves. The candlepower of a lamp in various directions is shown by distribution curves as in Fig. 20. The lamp is at the centre of a number of concentric circles equally spaced and marked with candlepower values, using a suitable scale. Equally spaced radial lines are drawn from the lamp as a centre, representing the different directions in which the readings are taken. These, of course, are all in the same plane, but this plane may be taken either vertically or horizontally through the centre of the lamp. For most purposes, however, a vertical plane is most convenient, since nearly all modern lamps give a uniform candlepower at all points in the horizontal plane. The curves shown in Fig. 20 are taken in a vertical plane with the lamp and reflectors pointing downward in the usual way. If we select any of the radial lines (or imagine one if there is none in the particular direction chosen) this line, by its angle with the horizontal or vertical, indicates the direction in which the candlepower is given, and by its length to the point where it meets the curve, the value of the candlepower in this direction. For example, referring to curve (*A*) Fig. 20, the candlepower in a horizontal line is 54 and in a vertical line directly below the lamp it is 90 cp. At 15° below the horizontal, the candlepower is 60 and so on. The other curves may be read in the same way.

* See paragraphs 79 and 119.

68. Systems of Illumination. Objects may be illuminated either by the direct or by the indirect method and the systems of illumination are classified according to the method used. With the **direct system**, the largest proportion of the light is directed on the surface to be illuminated without being reflected by walls or ceiling. With the **indirect system**, all of the light is projected to the ceiling or walls and is then reflected on the object to be illuminated. The **semi-indirect system** is a combination of the other two, in which the greater proportion of the light is reflected from the ceiling or walls, the remainder reaching the object directly through diffusing globes which form



a. Direct. *b.* Semi-indirect. *c.* Indirect.

Fig. 19.—Systems of Illumination.

a part of the lighting unit. In the direct system, a considerable part of the total light may be reflected from the ceiling and walls if they are light in color and if transparent reflectors are used on the lamps. Fig. 19 illustrates these different systems.

69. Requirements for Artificial Illumination. The planning of a satisfactory system of illumination requires consideration of (1) intensity of illumination, (2) steadiness of the light, (3) uniformity of illumination, (4) diffusion of illumination, (5) elimination of glare, (6) color-value of the light, (7) appearance, (8) efficiency. These are not given in the order of their importance, in fact it would be difficult to do so, as the relative importance of these factors varies with the kind of installation considered.

70. Intensity of Illumination. Since the purpose of all illumination is to enable objects to be seen, the first consideration is to provide sufficient illuminating intensity. Fortunately the eye can adapt itself to a wide range of intensities by changes in the size of the pupil of the eye, and adjustments of its internal parts. Changes in the size of the pupil occur rapidly and tend to adjust automatically the amount of light which enters the eye. A further adaptation is made internally to suit a variation in the amount of light admitted. In brief, the eye attempts to adjust itself to secure comfortable vision. If the intensity is too low, the object cannot be seen distinctly because not enough light enters the eye even when the pupil is enlarged as much as possible; on the other hand, if the intensity is too high, more light is admitted to the eye, even when the pupil is contracted, than can be accommodated, and this results in discomfort and sometimes permanent injury to the eye. We can see well and without discomfort with daylight intensities ranging from 1 to 500 foot-candles, while under artificial lighting conditions the eye will adjust itself to intensities from less than 1 foot-candle to several hundred foot-candles. A smaller range of intensities for artificial illumination will, however, meet the usual requirements. The best intensity depends upon the use which is made of the illumination. For reading, 3 to 4 foot-candles intensity gives satisfactory results, while for work requiring close application to detail, such as drafting or tool-making, high intensities of from 5 to 10 foot-candles are necessary. From 1.5 to 3.0 foot-candles is sufficient for warehouses, piers, etc. In street lighting, the average intensity is usually about 0.05 foot-candle. The values of illumination intensity required for proper vision are influenced greatly by the surroundings and the contrasts in intensity which exist. The methods of choosing a suitable intensity are discussed in Chapter 7.

71. Steadiness of the Light. If the intensity of illumination fluctuates, the pupil of the eye contracts and expands to adjust the eye to these changes. If the fluctuation is rapid and continuous, the muscles of the eye are fatigued and eye-strain results. Fluctuations such as occur with arc-lamps, while unpleasant, do not as a rule cause fatigue. If the fluctuations are rapid enough, the eye does not follow the changes, but adjusts itself to the average intensity. An example of this

character of fluctuation is the incandescent lamp operated by alternating current. At 60 cycles, no fluctuation can be detected by the eye, although there is variation in the candlepower of the light. If the frequency is decreased sufficiently, the eye is able to distinguish the variations in candlepower and we say the light *flickers*. The lowest frequency limit suitable for all purposes is about 35 cycles, although 25 cycles has been used satisfactorily for general illumination except where very small size tungsten lamps are used. Gas-filled lamps of a given ampere rating show less flicker than the vacuum-type lamps of the same rating. Lamps with metal filaments are less sensitive to fluctuation in voltage than carbon lamps of the *same size of filament*. The effect is more noticeable for a thin filament of a given substance than for one which is thick. The fluctuation in any case is less noticeable for low intensities of illumination.

72. Uniformity of Illumination. Until within a few years no attempt was made to secure even approximately uniform illumination for industrial or commercial lighting. Individual lamps, usually of 16 cp. size, were provided for each worker or machine and little or no attempt was made to provide general illumination of the room. Local lighting of this kind leads to deep shadows and excessive contrasts and is frequently a cause of eye fatigue and a fruitful source of accidents. It is now the custom to provide a fairly uniform general illumination, which may be supplemented by localized illumination when the nature of the work makes this desirable. If the foot-candles intensity is the same over the entire working surface or plane* the illumination is said to be uniform. It is never necessary to secure exact uniformity, since the eye cannot detect small variations.

73. Diffusion of Illumination. This should be distinguished from diffusion of the light from the lamp, which is considered in the next paragraph. If the light which illuminates an object comes from a number of different directions the illumination is said to be diffused. If all the light comes from a single source, for example a tungsten lamp, then the diffusion is poor and there are likely to be deep shadows and extreme contrasts in the illumination of different parts of the objects in the room. If the light comes from a number of sources, or if it is reflected

* This is usually assumed to be a horizontal surface 30 in. above the floor.

first to the ceiling of the room, thus increasing the light-giving area, better diffusion is secured, shadows are eliminated to a greater or less degree and the glare from polished surfaces is avoided. The highest degree of diffusion is secured with indirect or semi-indirect systems. With a direct system, satisfactory diffusion for most purposes can be secured if the lamps are closely spaced.

74. Glare. Glare is caused by excessive brightness of surfaces or objects in the field of vision. The worst examples of glare occur when the light source itself is in view or an image of the light source is reflected from some polished surface. When a bright surface is in the field of vision, the eye tries to adjust itself to the intensity of the bright surface; consequently an insufficient amount of light enters the eye from other objects and they are therefore seen only indistinctly, if at all. It is impossible, for example, to distinguish distant objects with a bright light nearby in the line of vision. Glare, besides reducing a person's visual power, may result also in eye-strain or, if long continued, may even permanently injure the eyes. All forms of modern illuminants, except the vapor-tube lamps, are so bright that the bare lamp should never be placed in the usual line of vision. If it is necessary to place the units where they are visible when looking in the usual directions, enclosing globes of opaque glass or frosted lamps should be used. With incandescent lamps, the reflectors usually enclose the lamps sufficiently to protect the eyes. Glare due to light reflected from a glazed paper, polished table top or even polished metal parts in process of manufacture may often be nearly as objectionable as the glare from an exposed lamp. Such surfaces therefore are to be avoided where possible, and in other cases diffusion of the light and a suitable direction for the light will eliminate the glare.

75. Color Value of Light. The color value of the light is frequently very important. Thus the nearly white light of the metallic-electrode arc lamp is particularly desirable for street lighting and is superior for this purpose to either the tungsten lamp or the flame-arc. On the other hand, for smoky or dusty places the yellow-flame arc seems to be particularly effective. For interior lighting, in general, the light of the tungsten lamp, which is slightly yellow, is particularly pleasing. In some cases daylight effects are required for interior lighting,

necessitating the use of special blue-glass tungsten units, Moore-tubes or other devices. Some lamps, for example the mercury-vapor arc, give a light so different from daylight that they could not be used where the color of light is important, as in stores, offices, etc.

76. Appearance. The appearance of a lighting installation is affected principally by the kind and shape of the reflector and the proportions of the fixtures. No attempt can be made here to cover in detail the requirements for securing a pleasing appearance, more than to outline a few fundamental rules which would apply particularly to commercial and industrial lighting installations. It would be obviously bad taste to use metal reflectors for lighting residences, stores, offices and similar places. On the other hand, glass reflectors are not in general suited for lighting factories.

77. Efficiency. In most commercial and industrial lighting installations, efficiency must be carefully considered. This does not mean, however, that we should use the cheapest reflector which can be purchased, nor does it mean that Gem lamps should be used because they cost less than tungsten. The installation which costs the least to install is generally the most expensive to operate, and usually has to be modified later at considerable additional expense. The time has passed when superintendents and managers are satisfied with a lighting installation which will be just sufficient to allow the operatives to continue their work. At present it is realized that a lighting installation which is designed with regard to proper intensity, shielding of the lamps and the other factors already mentioned, not only results in better satisfied workmen but also shows definite results in a material increase in quantity and an improvement in the quality of product turned out during the lighting hours. It also has a very important effect upon the number of accidents. The use of low-efficiency lamps such as the Gem or the ordinary carbon filament lamp for general illuminating purposes is never justified, as it can be easily shown that the saving in power effected by using high-efficiency lamps soon makes up the difference in the initial cost of the lamps. True efficiency therefore requires that proper reflectors and high-efficiency lamps be used and that the spacing and arrangement of the units shall be such as to fulfill the requirements given in the previous paragraphs.

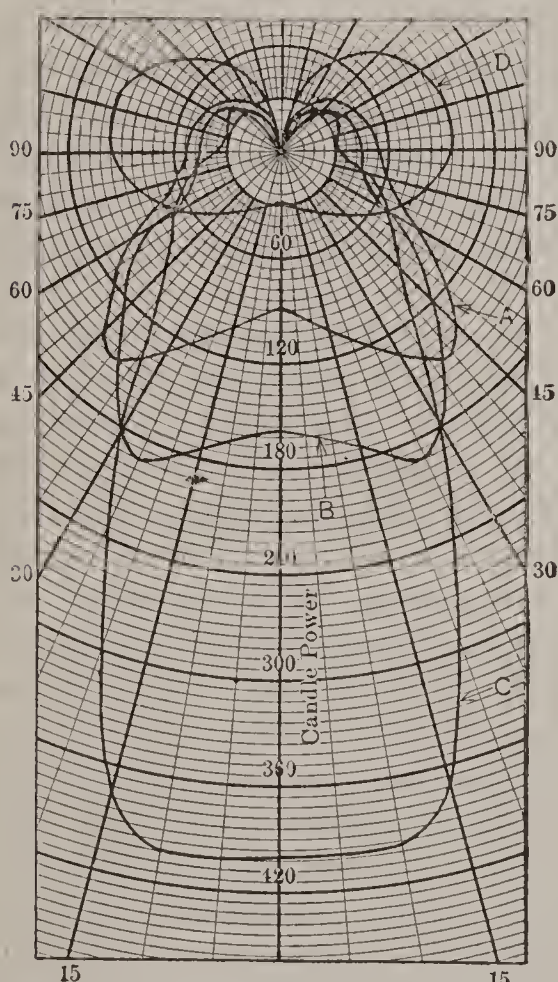
CHAPTER 5

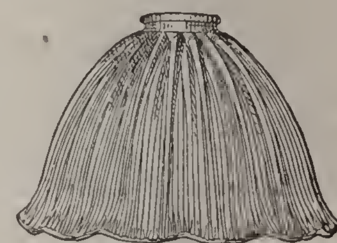
LIGHTING ACCESSORIES

78. Purposes of Lighting Accessories. The accessories used with artificial illuminants include reflectors, which are used primarily to redirect the light in a useful direction; diffusing globes and bowls, which serve principally to conceal the lamp and reduce the glare; and shades, which are used to improve the appearance of the unit.

79. Purpose of Reflectors. In order to use artificial illuminants effectively, the light produced must be directed in proper proportions in certain definite directions. To secure high efficiency, most of the light must be used to illuminate the working area, but frequently, in order to improve the appearance of the room and to prevent eye-strain, it is also necessary to illuminate the walls and ceiling. The proportion of light used for each purpose depends upon the system of illumination employed. In most cases, the light from a bare lamp, without reflector or other accessory, is not distributed properly. The first purpose of a reflector, therefore, is to redirect the light in the desired direction. Properly designed reflectors also enclose the lamp to a considerable extent and thus shield it from direct view. Glass reflectors allow a certain amount of light to pass through and thus give a more general distribution of the light. All reflectors, whether of clear or translucent glass or of metal, absorb some of the light which strikes them. Well-designed reflectors, however, do not absorb as much light as ordinary walls or ceilings, and since a large part of the total light produced by a lamp must be reflected in some way before it can become useful, it is necessary, for high efficiency, to provide reflecting surfaces which absorb a minimum amount of light. The effect of different types of reflectors upon the distribution of light from a lamp is illustrated in Fig. 17. The figures for the amount of light in different directions are representative of high efficiency reflectors of various types used for

direct lighting systems. The effect of reflectors upon the candlepower of a lamp in a given direction is shown in Fig. 20. These curves are for different styles of prismatic-glass reflectors for direct lighting. It will be seen that the bare lamp without reflector gives 30 cp. directly below the lamp and 70 cp. at 60° from the vertical. As the light given off at angles greater than




a—Extensive type


b—Intensive type


c—Focussing type

Fig. 20.—Light Distribution from Tungsten Lamp with Prismatic Glass Reflectors.

100-watt Mazda lamp operating at 1.02 watts per m.h. candle. *A*. Extensive reflector. *B*. Intensive reflector. *C*. Focussing reflector. *D*. Bare lamp.

60° cannot usually be employed very effectively, reflectors must be used to redirect the light. With reflector *A*, the vertical candlepower is increased to 90, while with reflector *C*, the candlepower is 400. The candlepower in the 60° line is of course decreased. If we consider the total light flux in the zone from 0° to 60°, we find that the lamp alone gives 159 lumens, while with reflectors *A*, *B*, and *C*, it is respectively 389, 433, and 469

lumens. The *total lumens* given off by the lamp are the same with or without the reflector, but the latter serves to direct a larger proportion of the total light flux in a useful direction. The bowls used for indirect and semi-indirect systems are also to be classed as reflectors. Reflecting surfaces are made of polished metal, silvered glass, prismatic glass, opal glass, enamelled metal and aluminum paint. Reflectors are used for both incandescent and arc lamps.

80. Purpose of Diffusing Globes. Globes or balls that entirely surround the light source are intended primarily to reduce the brilliancy of the light. In doing this, they also affect the distribution of light, the amount of this change depending upon the design of the unit. In some cases globes are also used to modify the color of the light. Globes may be made of prismatic glass; ground-glass, produced by acid etching or sand-blasting; and translucent or white glass of various kinds such as opal, alabaster, milk, etc. A considerable amount of light is absorbed by glass globes. For ground-glass, the absorption is about 10 per cent. Translucent glass absorbs from 15 to 30 per cent. This results in lower efficiency for the lighting installation. Diffusing globes therefore are chiefly employed where decorative effects are desired at the expense of efficiency; or where, by the use of gas-filled tungsten lamps, a reasonably high efficiency can be secured in spite of the light absorbed.

81. Shades. Shades are intended primarily for decorative effect, but they generally enclose the lamp to a considerable extent and thus shield it from view. Glass shades are made in a large variety of shapes and kinds of glass, and can be used to produce very artistic effects. All shades are very inefficient in their distribution of light. Metal shades are to be avoided, as reflectors which properly distribute the light as well as shade the lamp are preferable.

Accessories for Direct Lighting Systems *

82. Classes of Reflectors. Reflectors may be classified according to the manner in which they redistribute the light as follows: (1) extensive; (2) intensive; (3) focussing; (4) distributing; (5) angle. The characteristics of classes 1, 2,

* The following discussion applies more particularly to incandescent lighting.

and 3 are shown in Fig. 20. It will be seen that (*a*) gives the widest distribution of the light, (*c*) concentrates the light, and (*b*) gives a distribution intermediate between the other two. The **extensive type** (*a*) would generally be used for low ceilings, the **intensive** (*b*) for medium ceilings and the **focussing** (*c*)

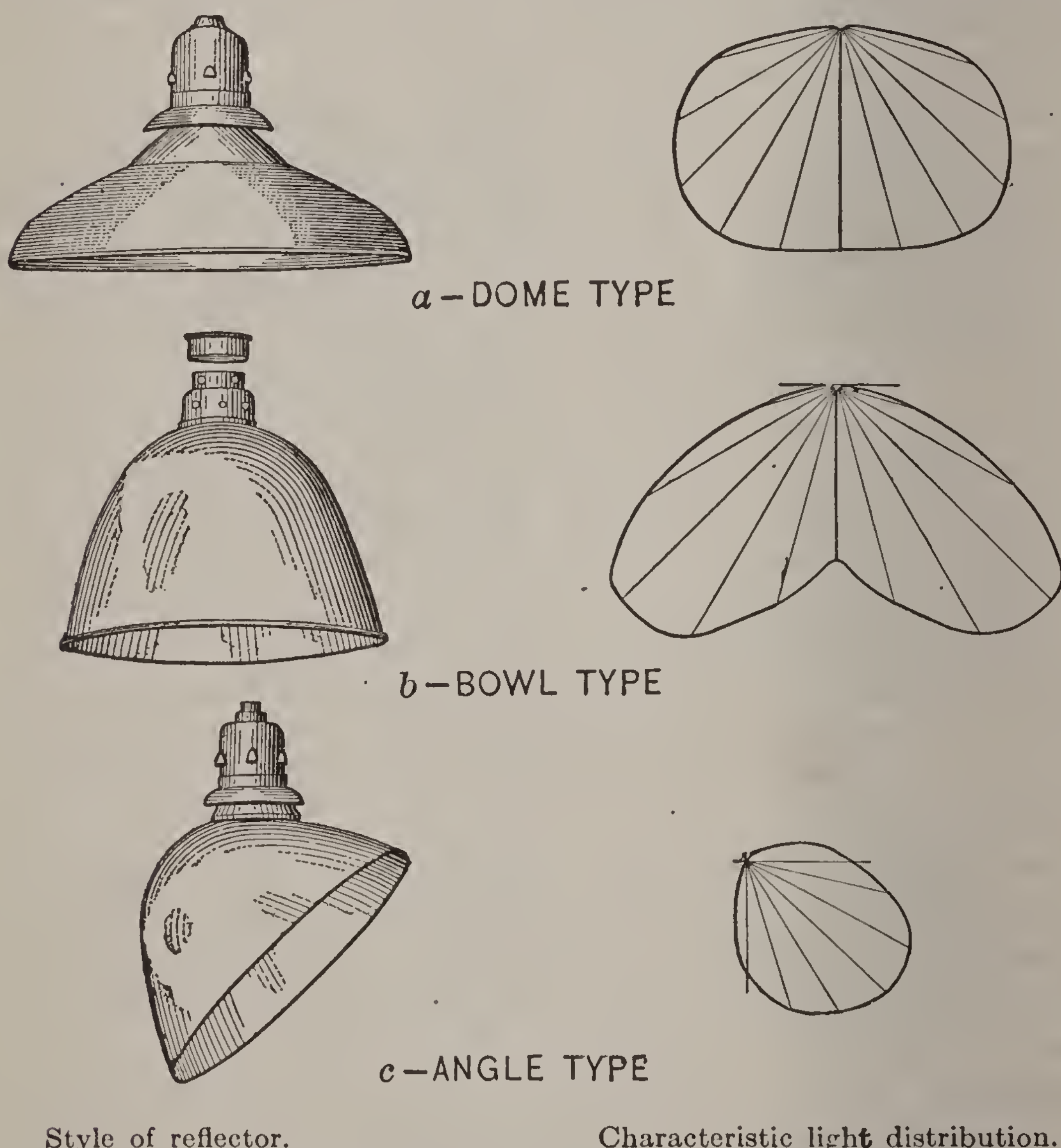


Fig. 21.—Typical Steel Reflectors for Tungsten Lamps.

for high ceilings. The **distributing type** gives a wider distribution than the extensive type and is used for large areas and for street lighting. Fig. 21*a* shows this type of reflector and gives the distribution curve. The **angle reflector** throws more of the light to one side, as shown in Fig. 21*c*. This type is used for lighting benches or particular parts of the work or machine, and for show windows.

83. Construction of Reflectors. Reflectors are made of metal, prismatic glass and white glass. **Metal reflectors** are usually made of steel, but aluminum and brass are also used to some extent. The **reflecting surface** on metal reflectors is usually white porcelain enamel, white paint or aluminum paint. **Enamelled steel reflectors** are the most satisfactory type of metal reflector for general use, as the surface has a high reflecting power, is permanent, easily cleaned, will resist acid fumes and heat, and will withstand exposure to weather in outdoor service. Reflectors having **white painted surfaces** are cheaper than the enamel type, but the surface rapidly deteriorates and they are therefore less efficient. The **aluminum finish reflectors,** when new, have as good reflecting power as the enamel type, and where the interior of the reflector is in the usual direction of vision, this style is preferable, as it diffuses the light and gives less glare. The aluminum surface, however, does not maintain its high efficiency during use, and the surface is difficult to clean. Steel reflectors with the aluminum finish are somewhat cheaper than the enamelled type. Metal reflectors are usually of the dome type (Fig. 21*a*), the bowl type (*b*) or the angle type (*c*). The bowl type encloses the lamp more than the dome type, but in most cases it is possible to obtain from 10 to 15 per cent more useful light when the dome type is used. Where it is possible, therefore, to mount the lamp high enough to be out of the normal direction of vision, the dome type should be used. This type of reflector gives a distributing form of light distribution (Fig. 21*a*), while the bowl type may be obtained in the extensive, intensive, or focussing types, giving distributions similar to those illustrated in Fig. 20, except that no light is directed above the horizontal. **Prismatic glass reflectors** are made from clear glass, with the reflecting surface composed of deep ribs on the outside. These ribs, to give high reflecting efficiency, must be carefully proportioned. In this type of reflector (Fig. 20 and Fig. 22*A*) a portion of the light striking the reflector passes through it and is directed against the ceiling and walls. The remainder of the light is reflected from the inside surface and is directed downward in a predetermined manner. In some cases, the **inside surface** of prismatic glass reflectors is given a **velvet finish** by etching the glass. This diffuses the light and reduces the glare. Prismatic-glass reflectors are made to give extensive, intensive or

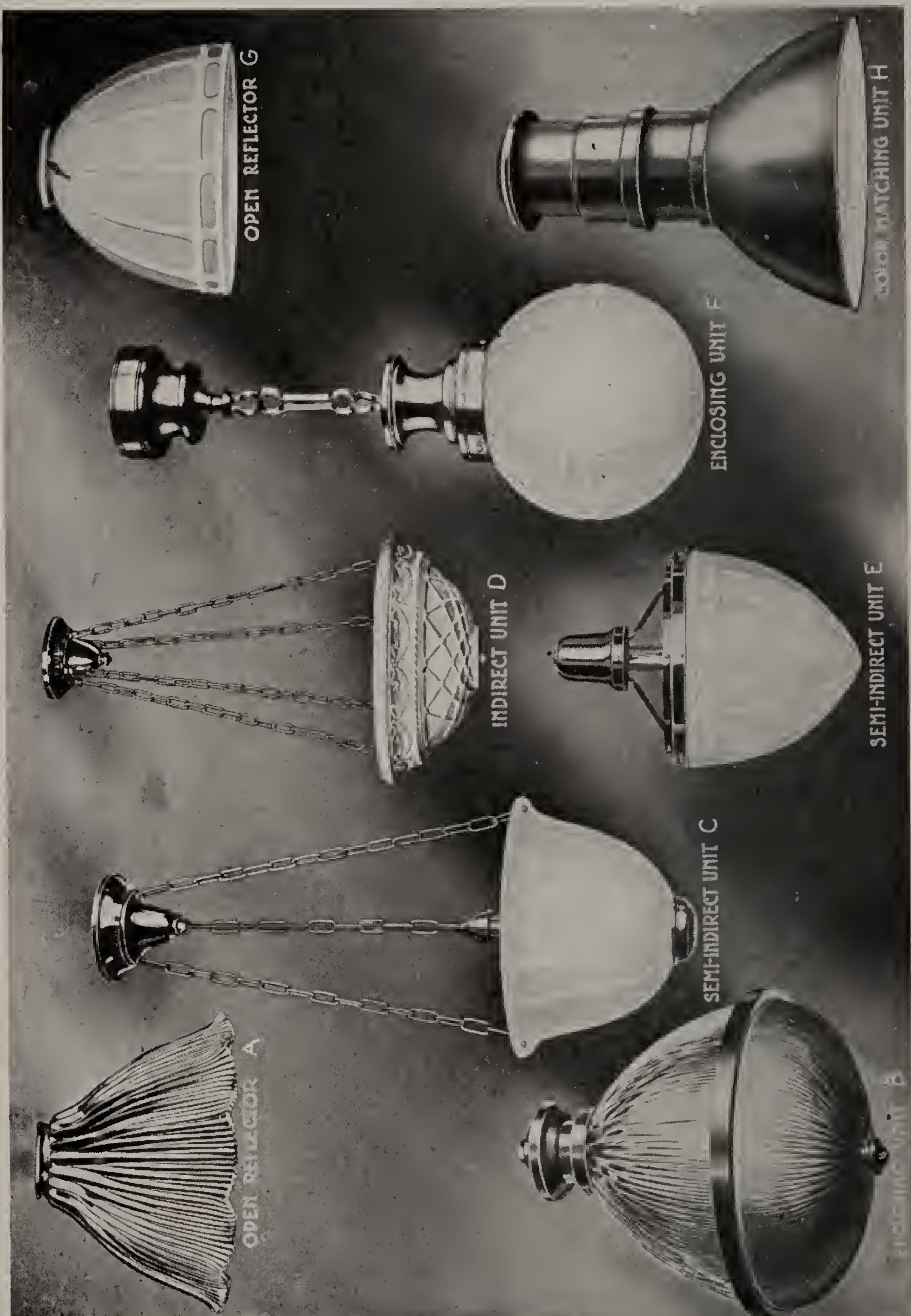


FIG. 22.—Typical Reflectors of Modern Design.

focussing distribution of light, the style chosen depending upon the height and spacing of the lamps, as explained in Chapter 7. They can also be obtained in the angle type. **White-glass reflectors** have smooth surfaces except where they are fluted to improve their appearance. They are made of many kinds of glass and in a wide variety of shapes. The forms generally used are the deep bowl (Fig. 22*g*) and the shallow bowl. In general, they are slightly less efficient than the prismatic-glass reflectors and do not control the distribution of light as accurately. The superior appearance of the white-glass reflectors results in their use for interior lighting where a specially pleasing and artistic installation is required, as in stores, offices, etc. These reflectors are made to give either a distributing or an extensive distribution. With the direct system, using white-glass reflectors, from 35 to 70 per cent of the light produced by the lamps reaches the working area, the value depending upon the color of the walls and ceiling. With metal reflectors, the useful light varies from 30 to 75 per cent. **Opaque-glass reflectors** are made with a silvered reflecting surface which is rippled or waved to partly diffuse the light and prevent streaked lighting effects. These reflectors are more efficient than either the translucent glass or metal reflectors, but like the latter, do not illuminate the ceiling of the room. They are also rather fragile when made in large sizes. For these reasons they find their chief application in window and show-case lighting. They are also used very effectively for indirect lighting units.

84. Size of Reflector. The size of a reflector varies with the candlepower of the lamp. A particular size of either a metal or glass reflector is suited for only one or two sizes of lamps. If other sizes are used, the lamp may be exposed too much and the distribution of the light will be greatly changed.

85. Holders for Reflectors. In order that the light may be properly distributed, the lamp must be correctly located in the reflector. If the lamp is placed too high or too low, the distribution of light will be altered and the desired result will not be obtained.* Care in the use of the proper holder is especially necessary with the prismatic glass reflectors, which are carefully designed to give a definite light distribution. The manufacturer's recommendations with regard to

* See paragraph 128.

holders should therefore be carefully followed. Fig. 23 (*a*) and (*b*) shows holders used principally for glass reflectors. Style (*a*) is used for lamps up to 100 watts and (*b*) for larger lamps having a skirted base. These holders attach directly to the shell of a standard, medium-base socket. On mogul-base sockets, the holder is generally attached permanently to the socket shell. With metal reflectors a form of holder shown in (*c*) is used. The notched top of the reflector is gripped by three prongs which are attached to the socket and are held together by a steel ring. This construction is used for both medium- and mogul-base sockets. For medium-base lamps a socket which is combined with the reflector in one piece

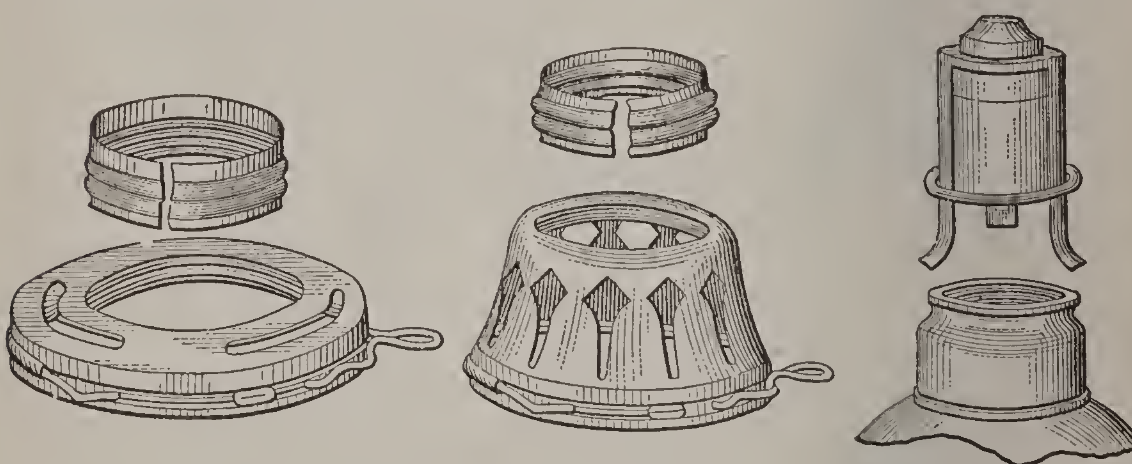


FIG. 23.—Holders for Reflectors.

a. Holder for glass reflectors with regular-base lamps. *b*. Holder for glass reflectors with skirted-base lamps. *c*. Holder for metal reflectors.

is frequently used. This is particularly adapted for industrial establishments and for outdoor service. Fig. 21 (*a*) and (*c*) shows this type of reflector. Fig. 21(*b*) shows the type which attaches to an ordinary lamp socket.

86. Heating Effect. As has been previously stated, most of the energy supplied to a tungsten lamp is given off in the form of heat. Thus with large tungsten lamps a very high temperature of reflector and socket is likely to result unless the unit is properly ventilated. The gas-filled tungsten units particularly need ventilation, not only because the units are usually of large size, but also because the heat is carried into the neck of the lamp by the circulation of the gas in the bulb. With glass reflectors, provision is made for venti-

lation by openings in the holders (see Fig. 23). If enclosing balls or hemispheres are used, openings must be provided at the top for ventilation, and sometimes a small hole is provided at the bottom of the ball. The one-piece metal reflectors (Fig. 21 (*a*) and (*c*)), which are closed at the top, are particularly likely to reach high temperatures when used with large gas-filled tungsten lamps. These reflectors are therefore equipped with porcelain receptacles designed to withstand a high temperature and are wired with asbestos-covered wire. It is usual also to provide ventilating openings in the neck of the reflector, where the receptacle is located. This arrangement is shown in Fig. 21 (*a*) and (*c*). Metal reflectors arranged to attach to ordinary sockets by means of shade-holders allow better ventilation, but cannot be used where they would be exposed to severe weather conditions. The so-called weather-proof sockets, made of a moulded composition which softens when heated, should not be used with large-size tungsten lamps.

87. Effect of Dust. Dust on reflectors reduces their reflecting efficiency. Tests show that after six months' use, under usual industrial conditions, tungsten lamps equipped with the reflectors indicated show a reduction in illumination of the working surface as follows: *

A—Dome-enameled steel reflector	15%
B—Bowl-enameled steel reflector	18
C—Dense opal glass reflector	20
D—Prismatic glass reflector	25
E—Light density opal glass reflector	32

It is apparent that reflectors and lamps should be cleaned periodically if a reasonably high efficiency is to be maintained.

88. Applications. **Porcelain-enameled steel reflectors** are the best type for general use in industrial lighting because of their high reflecting efficiency, their durability and the ease with which they may be kept clean. In localities where there is little dust, the **prismatic or white-glass reflectors** may be used to advantage, particularly if the units are mounted where they are not likely to be struck. Metal reflectors allow practically no light to reach the ceiling, but this is not objectionable in most cases. Glass reflectors, which allow a portion of the light to pass through and illuminate the ceiling, give a more pleasing

* From Bulletin No. 20, National Lamp Works of the General Electric Co.

effect. To obtain high efficiency from glass reflectors, however, the ceiling and walls must be light in color; therefore metal reflectors would be preferable where walls and ceiling are dark or where the lamps are mounted a considerable distance below the ceiling. **Metal reflectors** are best adapted for lighting steel mills, foundries, metal- and wood-working establishments, cement mills, tanneries, warehouses and power houses. **Glass reflectors** are better adapted for use in offices, drafting rooms. bakeries, laundries, printing establishments, clothing-manufacturing establishments, laboratories and similar industrial work. For **commercial lighting** in such places as railway stations, office buildings, stores, auditoriums, restaurants and school rooms, glass reflectors are generally employed. They are also commonly used in residences. Both the prismatic and the white-glass reflectors are used in commercial lighting. White-glass reflectors are made in a large variety of attractive designs. Prismatic reflectors are generally given a velvet finish.* The white-glass reflectors are superior in appearance to the prismatic reflectors and are therefore used, in spite of a lower efficiency, where the decorative effect is important. Fig. 22*A* shows the prismatic reflector and Fig. 22*G* a white-glass reflector of simple design. For outdoor lighting, metal reflectors of a weather-proof type are almost invariably used.

89. Diffusing Globes. For direct systems diffusing globes may be made either of prismatic glass (Fig. 22*B*), white glass (Fig. 22*F*), or of ground glass. They are usually employed instead of reflectors with gas-filled tungsten lamps, because of the great brilliancy of the lamp. Fig. 22 (*B*) and (*F*) shows the types used for commercial lighting in stores, offices, etc., and Figs. 28 and 63 the types used for outdoor service and industrial lighting. Since diffusing globes absorb a large amount of light, they are less efficient than reflectors for direct illumination. Globes made of a special kind of blue glass are sometimes used with gas-filled tungsten lamps, to give a light very closely resembling daylight. This is accomplished by absorbing a large proportion of the light produced by the lamp. This results, therefore, in very low efficiency and limits the use of this arrangement to color-matching, illumination of store windows and other special purposes, as the low efficiency would prohibit its use for general illumination. Sometimes, instead of a spe-

* See paragraph 83.

cial globe, a blue-glass plate is used, the lamp being mounted above the plate and backed by a metal reflector. (See Fig. 22*H*.)

Accessories for Semi-indirect Lighting Systems

90. Types of Reflectors. In the semi-indirect system, since the greatest proportion of the light is reflected from the walls and ceiling, the reflectors are always designed to entirely shield the lamp from view. The reflectors may take the form of a translucent glass bowl, a glass plate or even an ordinary direct type of glass reflector inverted so as to throw most of the light against the ceiling. The reflectors serve not only to direct the light against the walls, but also to diffuse that portion of the light which passes downward. This results in a greater diffusion of the light than in the direct system, with a resulting softening of shadows, and better uniformity of illumination in all parts of the room.

91. Distribution of Light. With the usual types of semi-indirect reflectors, about 80 per cent of the total light is directed above the horizontal plane, the balance passing downward through the reflector to the working surface. It is apparent that the light which is directed above the horizontal must be reflected either by the ceiling or walls before it can reach the objects to be illuminated. Surfaces ordinarily employed for walls and ceilings reflect from 80 to 20 per cent of the light, the higher value being for white or slightly tinted surfaces, and the lower figure for green or brown surfaces. It can be seen therefore that there is a considerable loss in efficiency when the semi-indirect system is used. Compared with the direct system, about 50 to 60 per cent more energy is required for the semi-indirect system, where the ceiling is light in color.

92. Translucent Bowls. The usual form of semi-indirect reflector consists of a translucent bowl hung directly below the lamp and entirely concealing it. The bowl is made of some form of white glass, such as alabaster, opal, etc., which glows with a very pleasing, soft light when the lamp is lighted. Fig. 22 (*C*) and (*E*) show this type of reflector. The bowl reflector is especially affected by dust, which rapidly collects on the inside surface, and thus reduces materially the efficiency of the unit and impairs its appearance, unless frequently removed.

93. Applications. The bowl-type of semi-indirect unit finds its principal application in rooms where specially artistic effects are required, such as restaurants, hotel lobbies, corridors, libraries, museums, ball rooms, churches, residences and offices. Gas-filled lamps are especially well adapted for use with this system, because of their high efficiency. The semi-indirect system is now used very extensively for commercial lighting owing to the recent improvements in the efficiency of the tungsten lamp. For store and office lighting it is particularly favored, because of the better appearance of the installation.

Accessories for Indirect-lighting Systems

94. Types of Reflectors. With the indirect system, the lamp is entirely shielded from view and all the light reaches the working surface by reflection from walls or ceiling. Silvered glass reflectors contained in bowls made of metal or plaster are frequently used. In some cases, the bowl is made of semi-transparent glass, which is rendered slightly luminous by means of small lamps, with the object of improving the appearance of the fixture. Fig. 22*D* shows one style of indirect bowl. A form of indirect lighting called **cove lighting** has been employed to some extent. With this arrangement, the lamps are concealed behind a cornice or cove located near the ceiling of the room. The efficiency of cove lighting is very low, as only 20 to 35 per cent of the light produced reaches the working area. For the bowl type of indirect system, the useful amount of light is greater, being 25 to 45 per cent of the total. These values do not take into account the effect of dust, which rapidly decreases the effectiveness of the indirect system unless the units are frequently cleaned.

95. Distribution of Light. The efficiency of the indirect system depends principally upon the reflecting efficiency of the ceiling and walls. It is apparent, from the discussion of this question in connection with the semi-indirect system, that the efficiency will be low when compared with the direct system. Even when using bowls with silvered reflectors, and light-colored ceilings and walls, the indirect system requires from 50 to 75 per cent more power than the direct system.

96. Applications. The indirect system is used for lighting drafting rooms, and occasionally for offices, stores and similar

places, but it is not so extensively used as the semi-indirect system. The objections to the indirect system are its low efficiency and lack of contrast in the illumination.* As a result, the indirect system requires a greater intensity of illumination than the direct system for the same kind of work.

Arc-lamp Accessories

97. Globes. These may be either clear glass, ground glass, or some form of white glass. Where the proper operation of the arc requires an enclosing globe, as for example, the ordinary enclosed carbon arc and the flame-arc, a clear **inner globe** is usually employed. An additional **outer globe** is used in many cases, either to shield the inner globe or to diffuse the light. Enclosed arc lamps for outdoor service usually employ clear outer globes, while for interior lighting a diffusing globe is generally employed to reduce the glare. Flame-arc lamps, in general, require diffusing outer globes of white glass, because of the intense brilliancy of the arc.

98. Reflectors. Direct-current enclosed arc lamps have a natural downward distribution of light (see Fig. 5*A*) and therefore reflectors are not usually required. A.c. arc lamps, since their distribution is wider (Fig. 5*B*) usually require reflectors for efficient use of the light. The flame-arc lamps have a wide distribution (Figs. 7*A* and *B*), but since they are high candle-power units which must light a large area the natural distribution is usually satisfactory. Reflectors are sometimes provided for industrial lighting so as to concentrate the light inside the 60° zone. (See Fig. 8.) Metallic-electrode arcs are not usually provided with reflectors, as the natural distribution (Fig. 10) is well adapted to the lighting requirements. A refractor, which serves the same purpose as a reflector, is, however, used with one type of metallic-electrode arc lamp (see Fig. 9*a*). The reflectors for enclosed carbon arc lamps may be either porcelain, enameled-steel, or white glass. The steel reflectors will withstand rough usage and are preferable, except where it is desired to illuminate the ceiling of a room.

* See paragraph 72.

CHAPTER 6

LIGHTING FIXTURES

99. Types of Fixtures. The term "lighting fixture" is used to designate the necessary supporting device which is required for properly mounting an incandescent lamp and its reflector. The fixture therefore includes the lamp-socket or receptacle,* suitable supports for this socket and the reflector. The entire combination of lamp, reflector, socket and supporting devices is called a **light-unit**. In some cases, supporting fixtures are employed with arc lamps and mercury-vapor lamps, but the following discussion applies only to fixtures used with incandescent lamps. Fixtures are of two general classes—ceiling and wall fixtures or brackets. Each class of fixture may be of several types; direct, indirect, or semi-indirect, depending upon the system of illumination for which it is designed. The fixture is subject to wide variations in design, since under this name is included all types, from the single-lamp pendant fixture or "drop," costing possibly a dollar, to the highly decorative fixtures containing many lamps and costing thousands of dollars. It is apparent that the fixture should support the lamp and reflector in such a position as to distribute the light in the proper direction. Modern commercial fixtures are carefully designed with this object in view. In the more artistic fixtures, however, efficiency is often sacrificed for the sake of a more decorative effect.

Fixtures for Direct Lighting

100. Single-lamp units. The simplest type of unit is the ordinary **pendant** or "drop," consisting of a socket with suitable reflector, a length of flexible twin conductor and a "rosette" adapted for attaching to the ceiling. Such a unit is shown in Fig. 24. For this fixture a socket tapped for $\frac{3}{8}$-in. pipe should

* See Chapter 16.

be used, and the conductor should be "reinforced cord" * in stores, etc., where not subject to rough usage. For factories, "packing-house cord" should be used. For lamps of 150 watts or less, No. 18 cord is satisfactory. For larger lamps, No. 16 or 14 cord should be used. The style of rosette used depends upon the system of wiring. A plain type of unit for use with conduit systems and suitable for **industrial lighting** is shown in Fig. 25. This consists of a one-piece steel

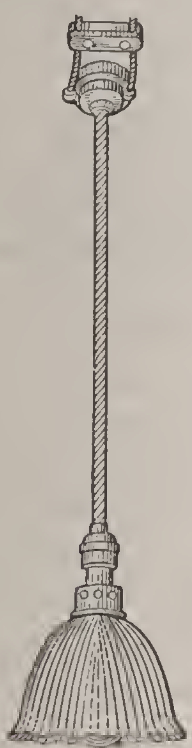


FIG. 24.—Cord Pendant.

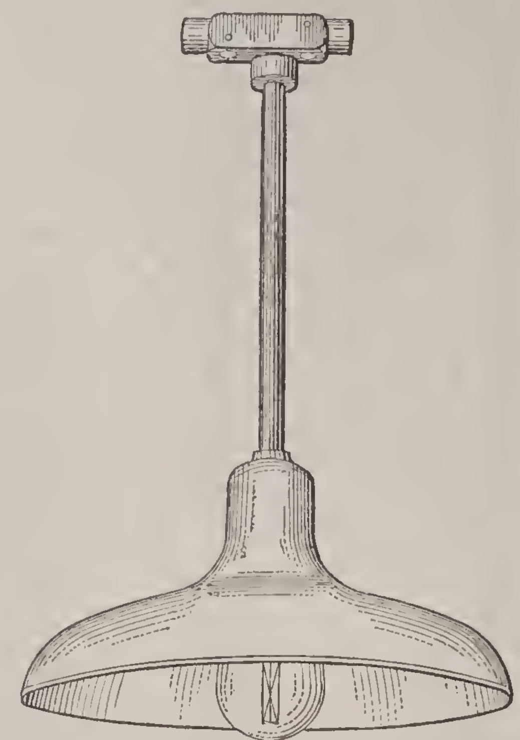
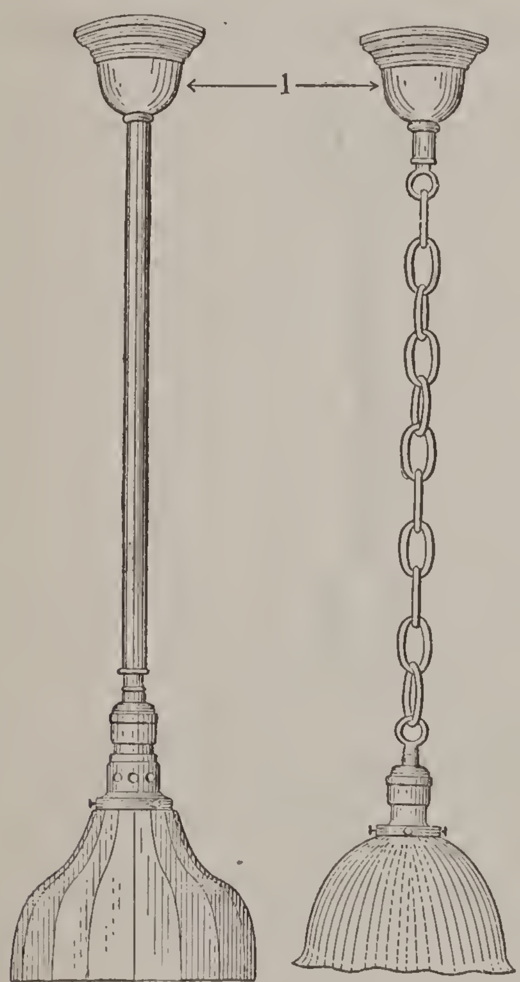


FIG. 25.—Rigid Fixture, Industrial Type.

reflector and a length of ½-in. iron conduit. Connection is made with the conduit system by means of a T-connection. This is used for exposed conduit work. For concealed work, a steel or cast-iron outlet box† would be used. If glass reflectors are used with this type of unit, a keyless socket and suitable reflector holder are provided in place of the combined reflector and socket shown in the illustration. These fixtures are usually wired with regular No. 14 wire carried directly to the socket. A **rigid fixture** of a more ornamental type is shown in Fig. 26*a*. This is adapted for concealed wiring systems and employs

* See paragraph 260. † See paragraph 227.

polished brass tubing instead of the iron conduit. A "canopy" (1) is used to cover the connections to the outlet box. In some cases these fixtures are made flexible by adding a link near the canopy (Fig. 22*f*). Fixtures of these kinds are usually wired with fixture wire or flexible cord. Another form of single-light unit is shown in Fig. 26*b*, where an ornamental chain is used instead of the tubing. This fixture is wired by means of flexible cord, which is colored to match the finish of the fixture, and is carried down the outside of the chain. Units of the type shown in Fig. 24 can be used where the lamp is located within reach and is to be controlled by means of a key socket. The same type of unit is also used with keyless sockets (as shown in the figure), where the lamps are mounted out of reach, but where an inexpensive installation is desired. The rigid type of fixture (Figs. 25 and 26*a*) is adapted for use only where there is no danger of the unit being struck. These fixtures should never be mounted so low that they are within reach from the floor. The more ornamental types (Figs. 26*a* and *b*) are used for commercial lighting in offices, stores, residences, restaurants, etc. For low ceilings, the unit may consist of a suitable receptacle with reflector (Fig. 27*a*). The dome type (Fig. 27*b*) is used for corridors and similar places. **Shock absorbers** were used extensively at one time on fixtures containing tungsten lamps, to reduce the filament breakage. The present form of wire-drawn lamp is, however, so rugged that shock absorbers are no longer necessary even where rigid fixtures are used. For



a. Rigid. *b*. Flexible.

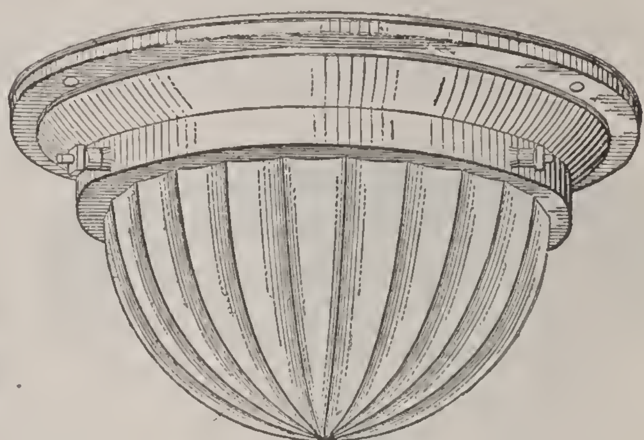
FIG. 26.—Single-lamp Units. Commercial Types.

1. Canopy.

installations where excessive vibration occurs, a flexible unit as shown in Fig. 24 is all that is necessary.

101. High Candlepower Units. The extensive use of large gas-filled tungsten lamps has called for specially designed light units. Reflectors are not used for these units unless they can

a. Reflector.



b. Dome.

FIG. 27.—Units for Low Ceilings.

be mounted high enough to be entirely out of the range of vision. It is more common to use diffusing globes* in order to shield the eye from the bright filament. For commercial lighting, the unit may be of the type shown in Fig. 22*B* and *F*. For industrial lighting, a combination of enclosing globe and steel reflector is often used. Such units are shown in Figs. 28 and 63. The unit shown in Fig. 63 is of a particularly substantial type and is well adapted for outdoor service. All of these units are thoroughly ventilated. A semi-indirect unit which can be used where the ceiling is dark, or where there are skylights, is shown in Fig. 29. This provides a suitable reflecting surface above the enclosing bowl, so as to properly direct the light down.

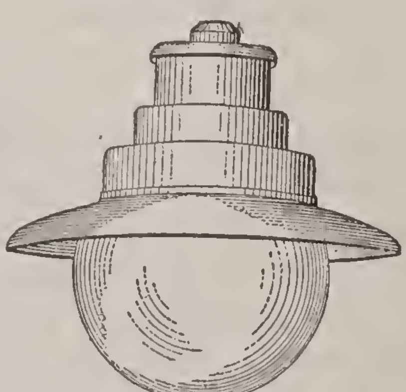


FIG. 28.—Unit for Gas-filled Tungsten Lamp.

102. Multiple-lamp Units. The multiple type of unit was more commonly used when the 16-cp. carbon lamp was the standard unit for incandescent lighting. At present, when

* See paragraph 89.

tungsten lamps may be obtained in sizes ranging from 8 to 1700 cp., the tendency is to use a single lamp for a fixture. From an efficiency standpoint, it is better to use single units having one large lamp rather than multiple units with several small lamps. Thus, if the proper illumination of a room required the use of about 100 watts for each fixture, it would be better in general to use a 100-watt lamp, with the proper reflector, than to use four 25-watt lamps with separate reflectors. Multiple fixtures are made in a great variety of attractive designs and are chiefly used for installations where artistic effects are important and efficiency is secondary. There is a tendency, however, to use multiple fixtures in many cases, where a suitable single lamp unit would be more satisfactory both from the standpoint of efficiency and of decorative effect. **Multiple fixtures** may take many forms, from the plain vertical stem with two or more branching arms at the bottom, to the enormous and costly fixtures or "chandeliers" used in lighting auditoriums, railroad waiting-rooms, etc. The modern multiple fixtures of plain types are designed with considerable attention to efficiency, with the lamps pointing vertically downward, and each provided with a high-efficiency reflector. The old design having the lamps projecting at an angle should not be used. Fig. 30*a* shows a modern type of fixture of good design. For fixtures of this type, keyless brass sockets for medium-base lamps would be used. Another type of small multiple fixture is the **shower type** shown in Fig. 30*b*. These fixtures usually have the lamps closer to the ceiling than the branch type (Fig. 30*a*). It is not usual to employ lamps larger than 50 watts in either of these types of fixtures. Glass reflectors or decorative

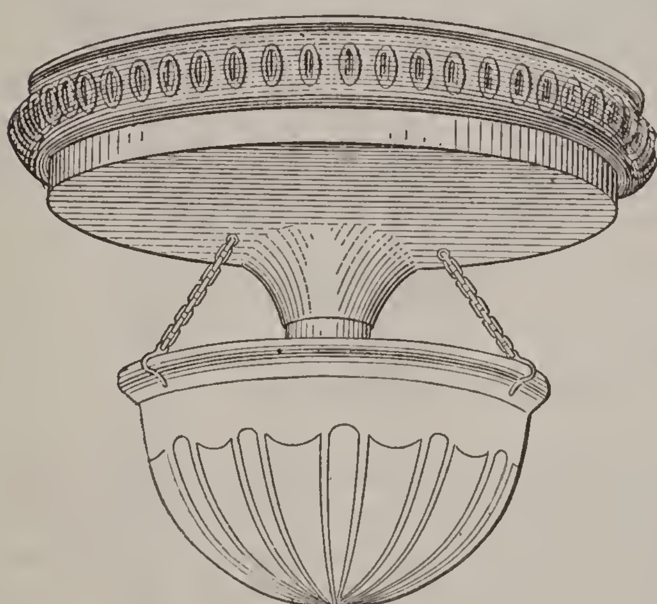


Fig. 29.—Semi-indirect Unit.
Used where the ceiling is dark.

shades are used with the shower type of fixture. Large multiple fixtures take so many forms that it is impossible to describe them in detail. The lamps are usually of small size, 25 or 50 watts, and no reflectors are employed. Generally the lamps are frosted to reduce their brilliancy. In some large fixtures, ground glass or opal balls are used, each enclosing a high-

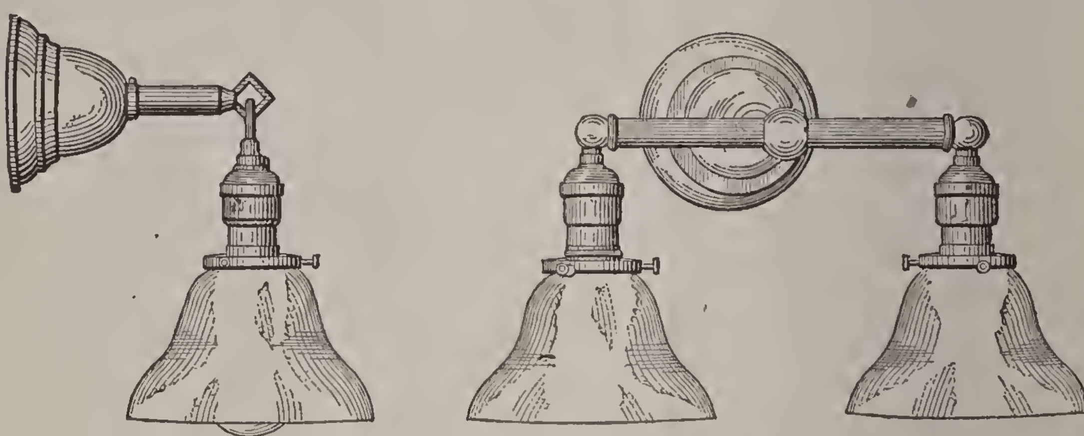
FIG. 30.—Multiple-lamp Units.

candlepower tungsten lamp. The wiring for multiple fixtures is generally concealed between the central supporting pipe and the ornamental enclosing shell, which is usually metal tubing.

103. Applications. Plain fixtures, such as are shown in Fig. 30, are best adapted for residences, offices, stores, small rooms in railway stations and similar places, although it should be

remembered that single-unit fixtures might be used for many of these places with as good or better results. Large fixtures are usually specially designed for a particular installation, and find their chief application in the illumination of auditoriums, public rooms in railway stations, libraries, museums, and large private residences.

104. Wall Brackets. Wall brackets are used to supplement the general illumination provided by the ceiling fixtures and to give a local illumination for special purposes. They also serve in some cases to improve the decorative appearance of an installation. Fig. 31 shows two types of wall brackets. Usually these brackets are equipped with ornamental shades or else



a- One Lamp *b* - Two Lamp

FIG. 31.—Wall Brackets.

the lamps are frosted and used without shades or reflectors. Wall brackets are chiefly used in residences, offices, restuarants, etc. With modern systems of lighting there is very little occasion for their use.

FIXTURES FOR SEMI-INDIRECT LIGHTING

105. The usual semi-indirect fixture is the bowl type, examples of which are shown in Figs. 22*C* and *E*. This type of unit consists of a white-glass bowl of high reflecting power supported directly below one or more tungsten lamps and entirely concealing them. The glass of which the bowl is made is semi-transparent, so that only a small amount of the light (about 15 or 20 per cent) passes through it, the greater proportion being reflected upon the ceiling. The units shown in the illustration employ a single lamp, but in some cases several lamps

are used. The choice between one or several lamps depends upon the design of the bowl. Another design is shown in Fig. 32. This employs a wide metal band which is backed by a mirror reflector. The central bowl is of white glass, which transmits a portion of the light and reflects the rest upon the ceiling. An inexpensive semi-indirect unit is obtained by using fixtures similar to Fig. 30*a* with the sockets and reflectors turned towards the ceiling. By this means, the greater part of the light is thrown upward instead of downward as would be the case with the reflectors in the normal position. This type of fixture has been successfully used in drafting rooms and offices.

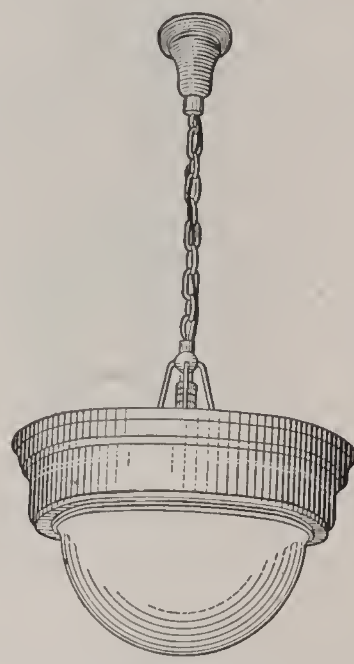


FIG. 32.—Semi-indirect Unit.

FIXTURES FOR INDIRECT LIGHTING

106. The usual type of indirect unit is similar to the bowl type, semi-indirect fixture, the chief difference being that the bowl is opaque. As was explained in paragraph 94, cove lighting was at one time used to some extent, but it is so inefficient that, at present, the bowl-type fixture has taken its place. The bowl is made of metal or plaster, and contains a suitable reflector, which, in the best types, is silvered glass. Either one large lamp or several small lamps may be used, depending upon the design of the bowl. Fig. 22*D* shows an efficient type of indirect unit.

107. Insulating Joints. Usually the insulation of the fixture wiring is considerably weaker than that of the remainder of the system. This is due to the design of the sockets and the weakness of the fixture wire used for connecting them to the circuit. This wire is not only smaller, but has a thinner insulation than that used on the rest of the circuit. Fixture wire must be used in most units, because of the small space available for running the wire. Short-circuits and grounds are therefore most likely to occur in the fixture wiring or in the socket. It is therefore desirable to localize trouble due to these defects by insulating the fixtures from the grounded

conduit system, gas pipes or other grounded metal objects. The insulating joints used for this purpose are couplings having threaded ends separated by mica or moulded insulation. Fig. 33 shows the construction of such a joint. The joint screws on to the end of the fixture and attaches to a threaded stud which is secured to the ceiling or wall. Where gas and electric fittings are combined in the same fixture, the insulating joint has an opening through the centre (Fig. 33*b*) for the passage of the gas. If the fixture is used simply for electric lamps, a solid joint of similar design is used (Fig. 33*c*). Red

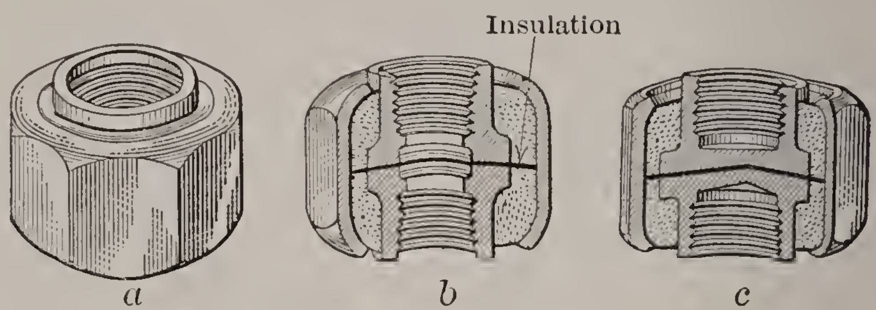


FIG. 33.—Insulating Joints for Fixtures.
b. For combination fixtures. *c*. For straight electric fixtures.

lead or graphite should never be used when connecting an insulating joint, since these substances are conductors of electricity and are likely to spread over the insulating surfaces and ground the fixture. Asphaltum paint is the most satisfactory material to use for this purpose. Insulating joints must be used * where fixtures are supported from outlets of systems using metal conduit, armored cable, or metal moulding, or when supported from gas piping or metal work. They are also required when fixtures are installed on metal walls or ceilings, or on plastered walls containing metal lath or on walls or ceilings of fireproof buildings. If suitable keyless sockets are used and No. 14 rubber-insulated wire is run directly to the sockets, the insulating joint may be omitted. No insulating joint is required, for example, when the fixture shown in Fig. 25 is used. **Canopies** (Fig. 26) are provided to cover the connections to the fixture and the insulating joint, if one is used. Canopies for fixtures having insulating joints must be provided with an insulating ring at the top, to keep the metal out of contact with the ceiling or wall. (Fig. 35.)

* Rules of the "National Electrical Code."

108. Methods of Supporting Fixtures. A substantial support for a fixture is important, particularly for large fixtures which may weigh several hundred pounds. All single-lamp

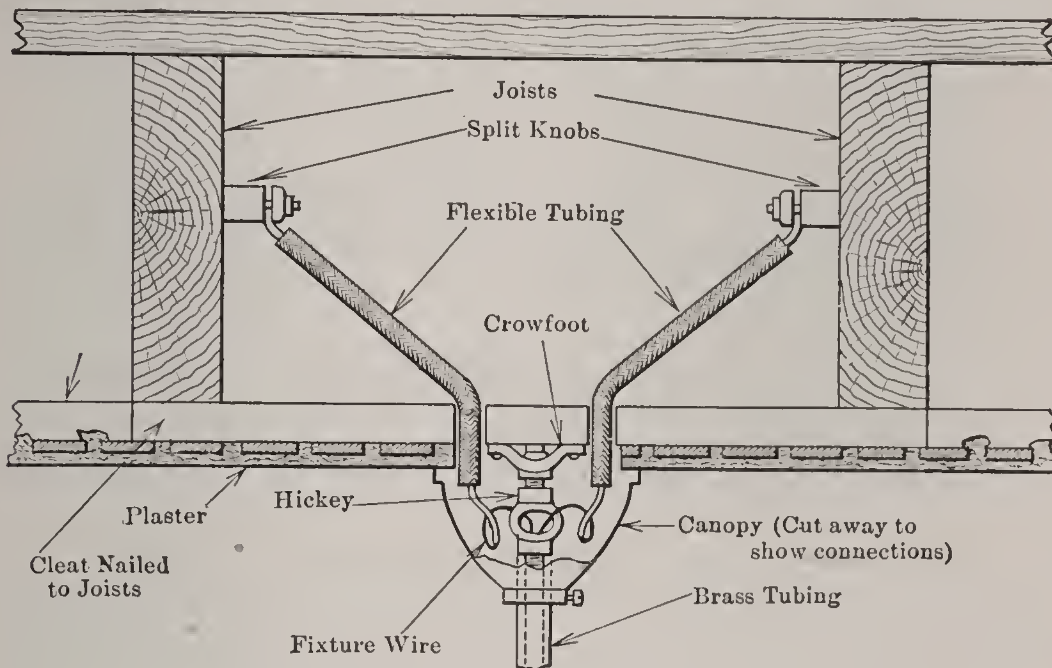


FIG. 34.—Support for Fixture.
Knob and tube wiring in frame house.

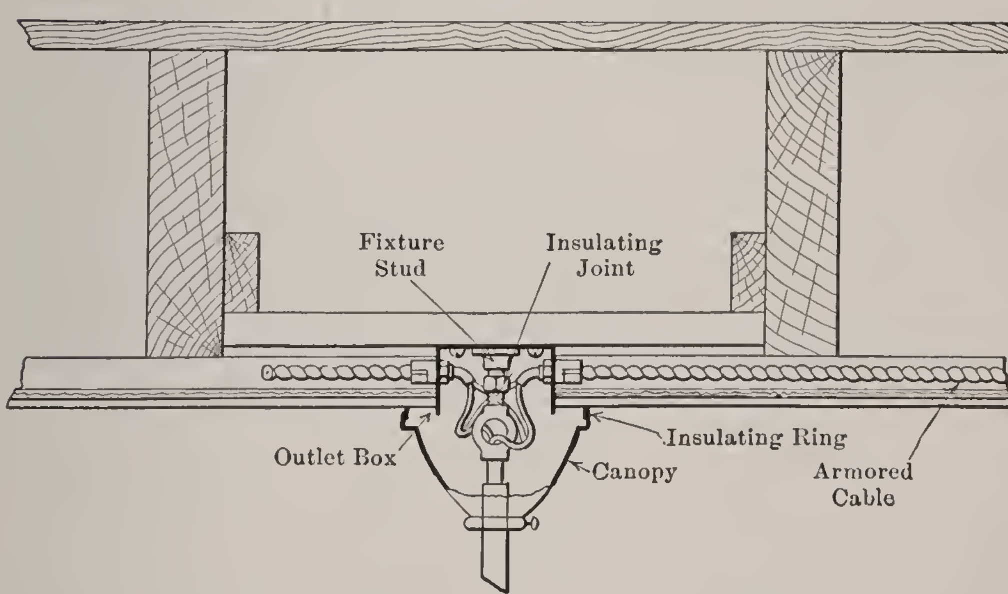


FIG. 35.—Support for Fixture using Outlet Box.
Arrangement shown is for armored cable. A similar method is used for rigid or flexible conduit.

fixtures and the ordinary sizes of multiple fixtures can be supported from $\frac{3}{8}$- or $\frac{1}{2}$-in. pipe fittings. Fig. 34 illustrates a satisfactory method of support for concealed "**knob and tube**"

wiring. A $\frac{7}{8}$-in. strip nailed to the floor timbers holds the flexible tubing covering the wires and supports the fixture by means of a "crow-foot." Connections are made to the fix-

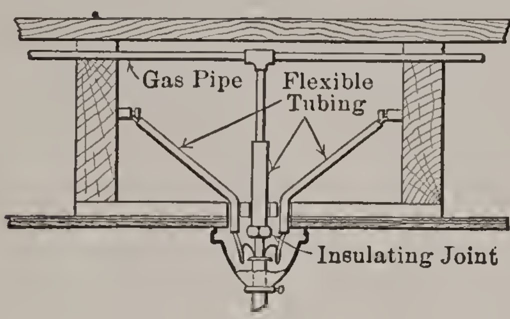


FIG. 36.—Support for Combination Fixture.
Knob and tube wiring.

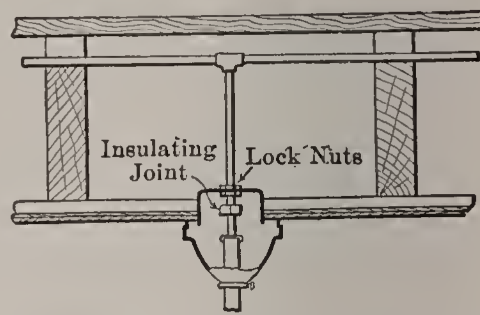


FIG. 37.—Support for Combination Fixture.
For conduit systems. Wires not shown.

ture wires at a point just below the ceiling line and the whole covered by the canopy. Where it is not possible to install a strip as shown (for example in the wiring of an old building)

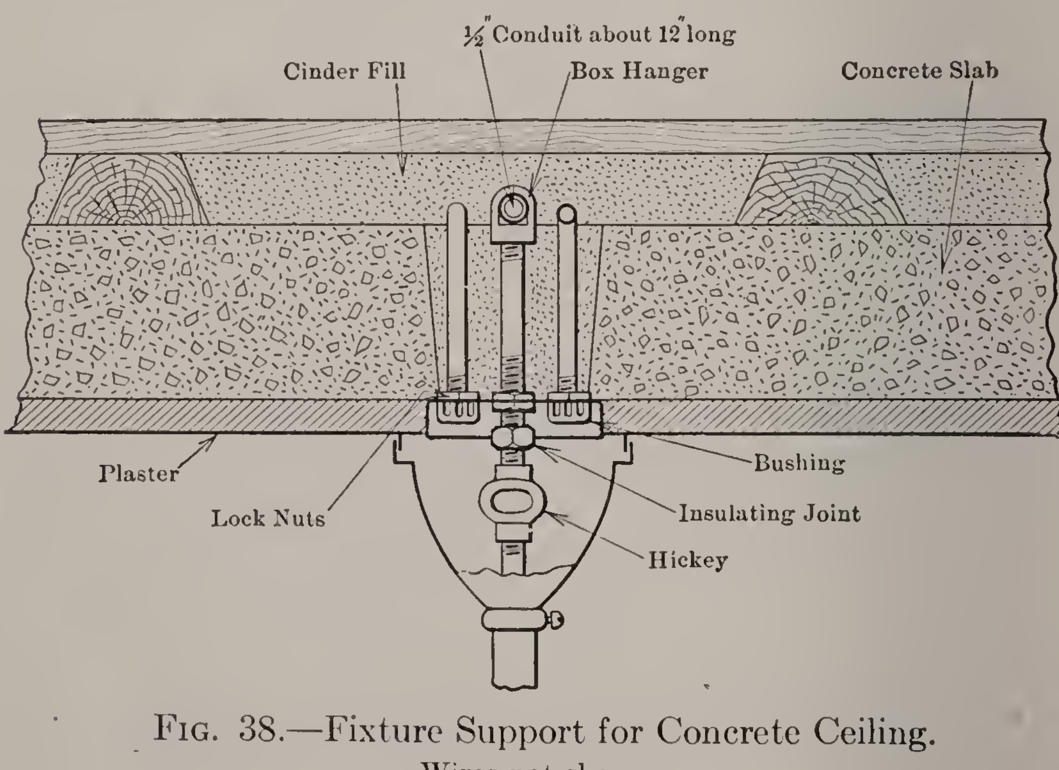


FIG. 38.—Fixture Support for Concrete Ceiling.
Wires not shown.

a wooden base block not less than $\frac{7}{8}$ in. thick may be fastened to the surface of the plaster. This arrangement could also be used for moulding work. Systems using rigid, or flexible

conduit, or armored wire are always provided with steel or cast iron outlet boxes* for each fixture. These boxes serve as a termination of the conduit, allow space for splicing the wires to the fixture circuits, and also in some cases provide a support for the fixture. In non-fireproof buildings, the boxes

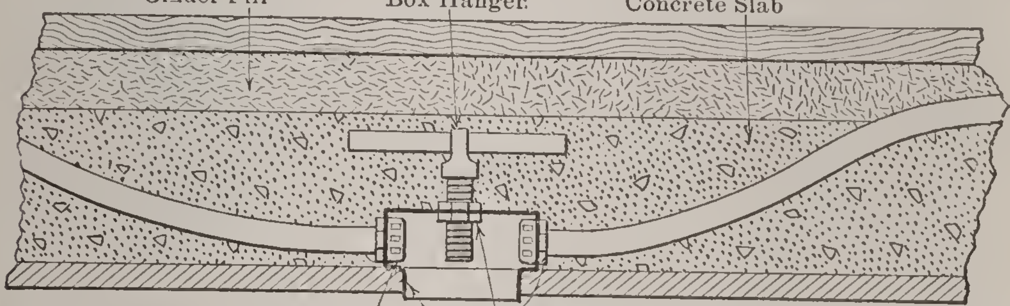


FIG. 39.—Fixture Support for Concrete Ceiling.
Conduit cast in.

may be screwed to a block nailed between the floor timbers in order to put the lower edge of the box flush with the finished plaster line. (Fig. 35.) The outlet box contains in the centre a threaded stud (Fig. 42) to which the fixture is attached. When a **combination gas and electric fixture** is installed,

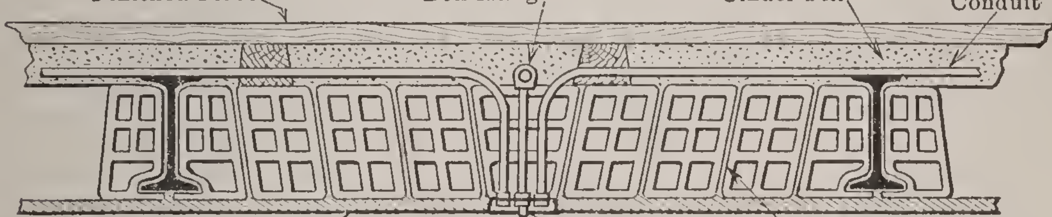


FIG. 40.—Fixture Support for Terra-cotta Ceiling.

arrangements like Figs. 36 or 37 are used. In Figs. 38 and 39 are shown suitable supports for **outlets in fireproof buildings,** where the plaster is placed directly on the bottom surface of the floor slab. The weight of the fixture is not carried by the box, but by a length of conduit which passes through the slab and terminates in an eye and a short length of conduit forming

* See paragraph 227.

a cross-bar. This is concealed under the finished floor. The outlet box is supported from the conduit holding the fixture by means of the lock units. The arrangement in Fig. 38 uses a shallow box which is placed directly against the floor slab.

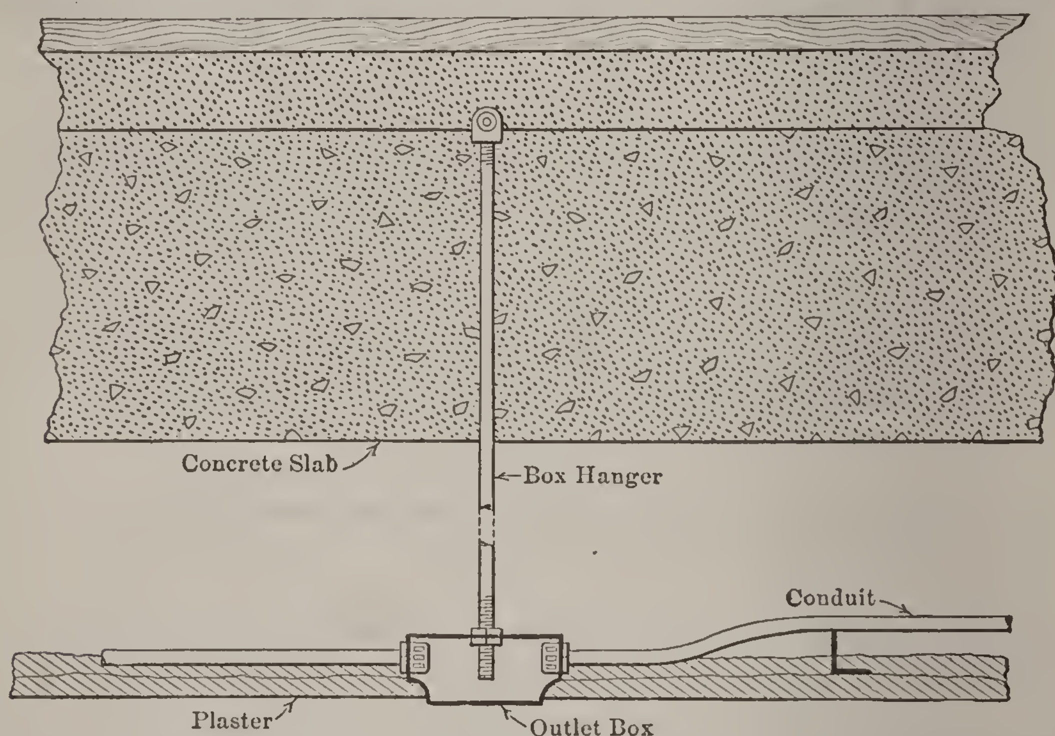


Fig. 41.—Fixture Support for Furred and Plastered Ceiling.

The other construction (Fig. 39) employs a deep box, which is set in the concrete. The latter method is more commonly used where the box and conduit are installed on the forms and the concrete cast around them. When a shallow box (Fig. 38) is used a wooden plug can be placed in the form to provide an opening for the installation of the conduit after the concrete is in place. If desired, however, the conduit can be installed before the concrete is placed, as in the other construction. Fig. 40 shows an arrangement for floors built of hollow tile. Where a "hung ceiling" is used, an arrangement similar to Fig. 41 may be used. A deep box is employed and the conduit enters on the side instead of the top. The supporting pipe may be $\frac{1}{2}$ in. or $\frac{3}{4}$ in. for large fixtures. The types of supports

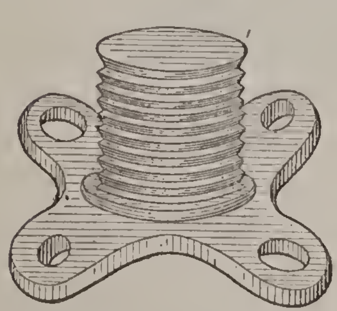


Fig. 42.—Fixture Stud.

shown in Figs. 38 to 41 are very satisfactory for fixtures of the usual sizes. For very small fixtures, a threaded stud (Fig. 42) may be used. This is attached directly to the outlet box, which must be securely fastened to the ceiling. Very large fixtures are supported from a chain which is attached to a suitable beam framed into the steel work of the building. These fixtures are usually located so high that they cannot be reached by ladders from the floor. Arrangement must therefore be made to lower the fixture for cleaning or renewal of lamps. **Wall fixtures** or brackets can be supported from studs (Fig. 42) in the outlet box unless they are very heavy, when they must be bolted to the wall.

CHAPTER 7

PRACTICAL METHODS OF CALCULATING INTERIOR ILLUMINATION

109. The Problem of Interior Illumination. At the present time the advantages of a satisfactory lighting system are very generally appreciated. Since, however, the wiring is usually installed in iron conduit, and is frequently concealed in the walls and ceilings, proper attention should be given at the start to the design of the lighting system to avoid expensive changes after the system has been put in operation. For some places, such as libraries, museums, theatres, large residences and high-class stores, the lighting system should harmonize with the furnishings and furniture and the illumination should assist in producing the desired decorative effect. Installations of this kind require individual treatment by lighting experts and will not be considered here. For industrial lighting and many cases of commercial lighting, efficiency and cost of the installation are of first importance, and decorative effects, while they should not be entirely neglected, are of secondary interest. Standard designs of reflectors and fixtures can be used in such cases, and by using data from similar installations it is comparatively easy to secure a satisfactory lighting installation. Only this kind of lighting problem will be considered here. The factors which are involved in planning a lighting system are:

1. *Class of lighting*, whether industrial or commercial. This obviously depends upon the use which is made of the illumination.
2. *Method of illumination*, whether localized, general or a combination of the two.
3. *System of illumination*, whether direct, indirect or semi-indirect.
4. *Type of lamp* to be used, whether arc, incandescent or vapor tube.

5. *Intensity of illumination,* which depends upon item (1).
6. *Power Required.* This is affected by all of the foregoing items.
7. *Size of Light Unit.* This depends upon the size of the room.
8. *Location of light units,* which requires consideration of the proper spacing and height of mounting.
9. *Reflectors or Globes.*

(1) Class of Lighting

110. Before a lighting system can be intelligently designed, information regarding the kind of work carried on must be secured. The location of machines or furniture should be determined as far as possible, and the height of ceiling and size of room must be known. The color of walls and ceiling should also be considered. Based on the character of the work, the lighting may be classified as either industrial or commercial. **Industrial lighting** includes all applications where efficiency of illumination is of the greatest importance, and where decorative effect and appearance of the lighting units is relatively unimportant. In this class would be included factory and warehouse lighting. **Commercial lighting** includes applications where more attention must be paid to securing an installation which will harmonize with the decorations and furnishings of the rooms. In such places, efficiency, by which is meant the relative power consumption, may be, to a certain extent, sacrificed for the sake of improved appearance. This is secured usually by careful attention to the proportion of the fixtures, and to the effect of the illumination upon the decorations of the room. To this class belongs the lighting of office buildings, stores, restaurants, hotels, libraries, museums, railway stations, residences, etc.

(2) Method of Illumination

111. Localized lighting was at one time very commonly employed and is in fact the simplest way of utilizing the light. With this method an incandescent lamp of small candle-power is provided for each worker or machine, and no attempt is made to provide general illumination of the room. An arrangement of this kind is necessary in some cases, for example

when machining the interiors of castings or boilers, or in other places where a general illumination could not penetrate. It can also be used to light small areas which are widely separated. An installation of local lighting is likely to be expensive to install owing to the large number of units employed, and expensive to maintain because of the chance for damage to the units by careless handling. Furthermore a change in the location of machines would usually require expensive changes in the lighting system. The use of this method should there-

FIG. 43.—Example of Localized Lighting.
(National Lamp Works of G. E. Co.)

fore be confined to places where general illumination cannot be used, or where it can be combined with a moderate general illumination to produce a high light intensity for special purposes. The second of these two applications is more commonly found at present (see Fig. 43).

112. General Lighting. In this method practically uniform light intensity is produced over the entire room. The light units are equipped with efficient reflectors to properly control the light and are evenly spaced, without regard to the location of machinery or furniture (Fig. 44). Before the introduction of tungsten lamps only arc lamps were used for general illumina-

tion because of the large amount of power required when carbon lamps were used. General lighting is best adapted to large rooms free from obstructions, where the workers are located close together, so that the same illumination intensity is required over practically the entire room. It is also well adapted for stores, offices and similar places, where there are possibilities of frequent rearrangement of the furniture, etc.

FIG. 44.—Example of General Lighting.

Installation of 250-watt lamps with 16-foot mounting height. (General Electric Co.)

High-candlepower tungsten lamps, arc lamps, and mercury-vapor lamps may all be used for general lighting.

113. Localized general lighting or group lighting is a modified form of general lighting. High-efficiency light units are used, but they are not uniformly spaced and no attempt is made to secure uniform illumination. Instead, the units are spaced with particular reference to the machines, thus providing the proper intensity at the working points and a lower intensity at other places. This method is particularly adapted for rooms where there are a number of similar machines, arranged

in rows, as in machine shops, weave rooms, etc. (Fig. 45). The same kind of units may be used for this method as for general illumination. Group lighting is more economical than general lighting where a high intensity is required only over the machines. There is of course no sharp dividing line between the group system and the general lighting method, since a particular installation may tend towards one or the other, depending upon the arrangement of the units. In some

FIG. 45.—Example of Localized General Lighting.

Note the reflection from the goods to the ceiling. (Illuminating Engineering Society.)

cases a combination of **general and localized lighting** is desirable. For this method sufficient general lighting is provided to illuminate distinctly the various objects in the room while lamps of small size are provided for each worker. Such an arrangement is desirable where a very strong light is required upon the work and where it would be difficult to secure this by the general lighting without producing troublesome shadows. This method is particularly useful in lighting sewing machines where each worker is provided with a small tungsten lamp in a metal reflector located on a flexible arm which can be adjusted

to throw a strong light directly upon the work. This arrangement can also be used to advantage for fine machine work, inspecting, assembling, office work, etc. The particular method to use depends somewhat upon the requirements of the installation. Tables 8 and 9 indicate the usual practice.

(3) Systems of Illumination *

114. The direct system is usually employed for **industrial lighting,** since it requires the least power to produce a given amount of illumination. Occasionally, however, an indirect system is used for work rooms with low ceilings, or where shadows must be eliminated, as in drafting rooms. The direct system is also used in many **commercial installations** where efficiency is of great importance.

115. The semi-indirect system is at present used very extensively for **commercial installations** where a reasonably high efficiency is desired, but where it is also necessary that the light units shall harmonize with the furnishings of the room. The numerous designs of semi-indirect bowls and supporting fixtures now on the market allow the use of units which are not only efficient but are also effective in improving the appearance of the installation. The principal applications of this system are in the better classes of stores, restaurants, residences, hotels, etc.

116. The indirect system finds only a limited use, for drafting rooms, hotel bed rooms, etc. Where a direct system is not used, the semi-indirect system is in general preferable to the indirect system, both because of the slightly better efficiency of the latter and because of the better appearance of the installation. Neither of these systems can be effective unless the ceiling is light in color. The particular applications of these systems are indicated in Tables 8 and 9.

(4) Type of Lamp †

The size of room, height of ceiling and character of work performed all have a bearing upon the selection of the type of lamp. **Tungsten lamps** are now made in sizes to suit all kinds of commercial and industrial lighting requirements and are used

* See paragraph 68.

† See Chapters 2 and 3 for descriptions of lamps.

much more extensively than any other kind of lamp. They are practically the only type now used for commercial lighting. **Flame-arc lamps** are especially well suited for use in smoky places or dusty locations because of the penetrating quality of the light, and hence they have been used extensively in steel mills, foundries, etc. The gas-filled lamps are, however, now being used in these places and there is a tendency at present to use them in place of flame-arcs. **Mercury-vapor lamps** are well adapted for some kinds of industrial lighting because of the color of the light. In machine shops and where varnishing and finishing work is done, they seem to be especially desirable.

(5) Intensity of Illumination

117. The importance of a suitable intensity has been discussed in paragraph 70. There is a decided tendency at present to use rather high intensities. In **industrial establishments** there are good arguments for such a practice because it increases the amount of finished product, decreases the quantity of spoiled work and reduces the number of accidents. Due to the importance of this subject a "Code of Lighting" has recently been issued* to serve as a guide for factory lighting.

Approximate Illumination Intensities for Industrial Lighting.

Class of Work.	Foot-candles.	
	Minimum.	Desirable.
Storage, passageways, stairways and the like	0.25	0.25– 0.5
Rough manufacturing and other operations. .	1.25	1.25– 2.5
Fine manufacturing and other operations. . . .	3.50	3.50– 6.0
Special cases of fine work.	. . . .	10.00–15.0

These values are the average intensities on a horizontal plane on a level with the work. The intensities given are only general values and for a particular problem more definite information is required. Tables 8 and 9 give data of this kind for lighting with tungsten lamps. The **operating cost** of a suitable lighting system is only about $\frac{1}{2}$ of 1 per cent of the total operating costs for industrial establishments and only about 1 per cent of the total sales in the case of stores, and hence is a very

* Illumination Engineering Society, 1915.

small item in the total cost of doing business. For stores and office buildings the lighting system serves as one form of advertising. There are therefore very good arguments for using a satisfactory lighting system.

118. Choosing a Suitable Intensity. It will be noted that in both Tables 8 and 9 a range of intensities is indicated. Where first cost of installation is important or where the character of the work is such that the highest intensity is not required, the lower value should be used. The intensity used may be influenced considerably by certain peculiar conditions of the installation, and the tables should not be used blindly without taking these into account. Thus it is found that an intensity which is entirely sufficient for proper vision, if used alone, may be insufficient when supplemented by **daylight.** If therefore the artificial lighting system is to be used when daylight is also employed (for example late in the afternoon) the intensity must be increased somewhat. It is also apparent that the illumination required for work on **dark material** is greater than is required for light material. The intensity necessary for local lighting is usually greater than that where general lighting is used. This is due to the strong contrasts in intensity which are likely to exist when **local lighting** is used. It is always well to be somewhat liberal in choosing the illumination intensity, since the tables are based on clean lamps and reflectors. An allowance should therefore be made for **depreciation due to dust.** The amount of this depreciation is indicated in paragraph 87. Where conditions are such that the reflectors may be regularly cleaned, an allowance of at least 10 per cent excess illumination should be made, while for installations which will probably not be cleaned regularly, as much as 25 per cent excess should be allowed. In Tables 8 and 9, where general illumination (G) is indicated, the specified intensity is the average over the entire room on a horizontal surface at the usual height of the work. This surface is called the **working plane.** Usually this is taken as 30 in. above the floor. This illumination is secured by light-units uniformly spaced over the entire room. Where local illumination (L) is specified, the intensity given is that at the point on the machine to which the light is directed. Where combined local and general illumination (G and L) is specified, the value given is for the general illumination only. The amount of local illumination is

indicated by specifying a definite size of lamp. Where group lighting (*L-G*) is used the values are those on the work. This is produced by lamps located with particular reference to the machine, and recommendations for the size of these lamps are given in the tables. If uniform illumination is desired instead of group lighting, the values of foot-candles in column 3 of Table 9 can be used as a guide.

119. Method of Securing Uniform Illumination. If general lighting (giving uniform illumination) is to be provided by means

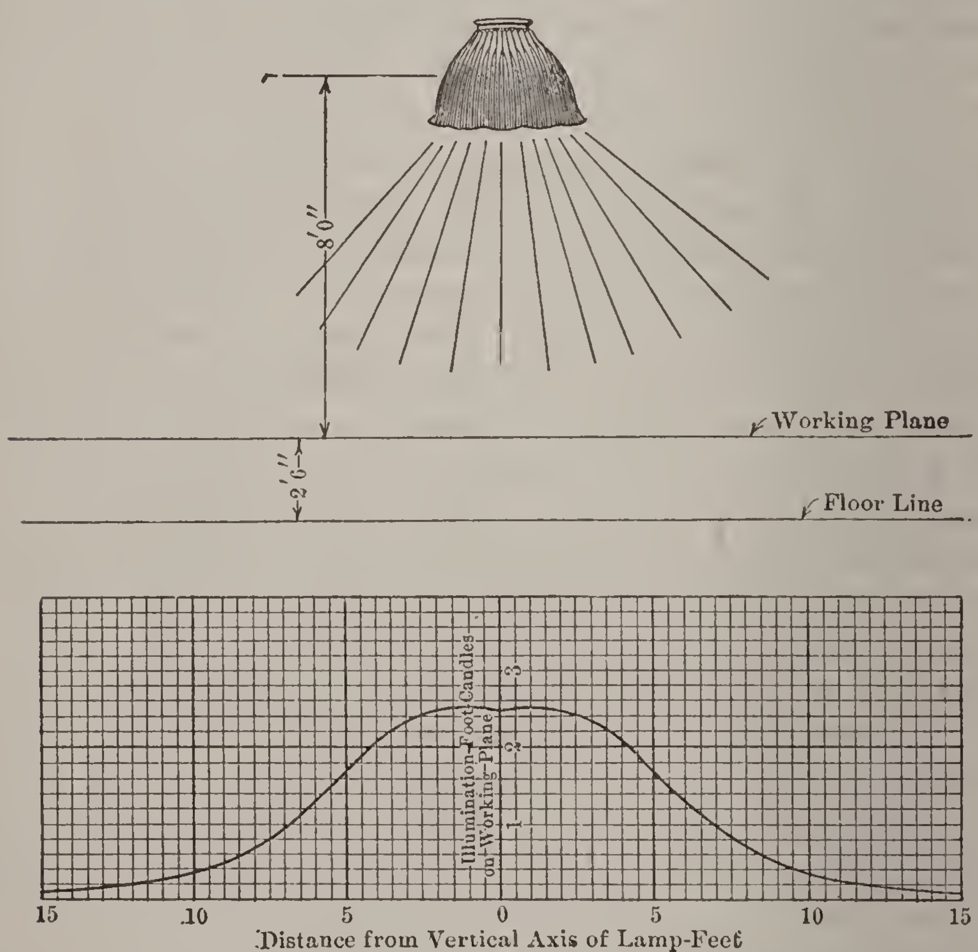


FIG. 46.—Illumination Produced by a Single Tungsten Lamp.
(100-watt Mazda B lamp with intensive, prismatic reflector.)

of tungsten lamps, there is a definite relation between the spacing and height of units and the style of reflector used. Consider first a single lamp equipped with a reflector for direct lighting. Fig. 46 shows the intensity on a horizontal surface 8 feet below the unit, neglecting the effect of walls and ceiling. Directly beneath the lamp, the intensity is 2.45 foot-candles, while 5

ft. away from this point it is 1.69 foot-candles, and at 10 ft. it has dropped to 0.38 foot-candle. It is apparent that in a room lighted by a single lamp, a wide variation of illumination inten-

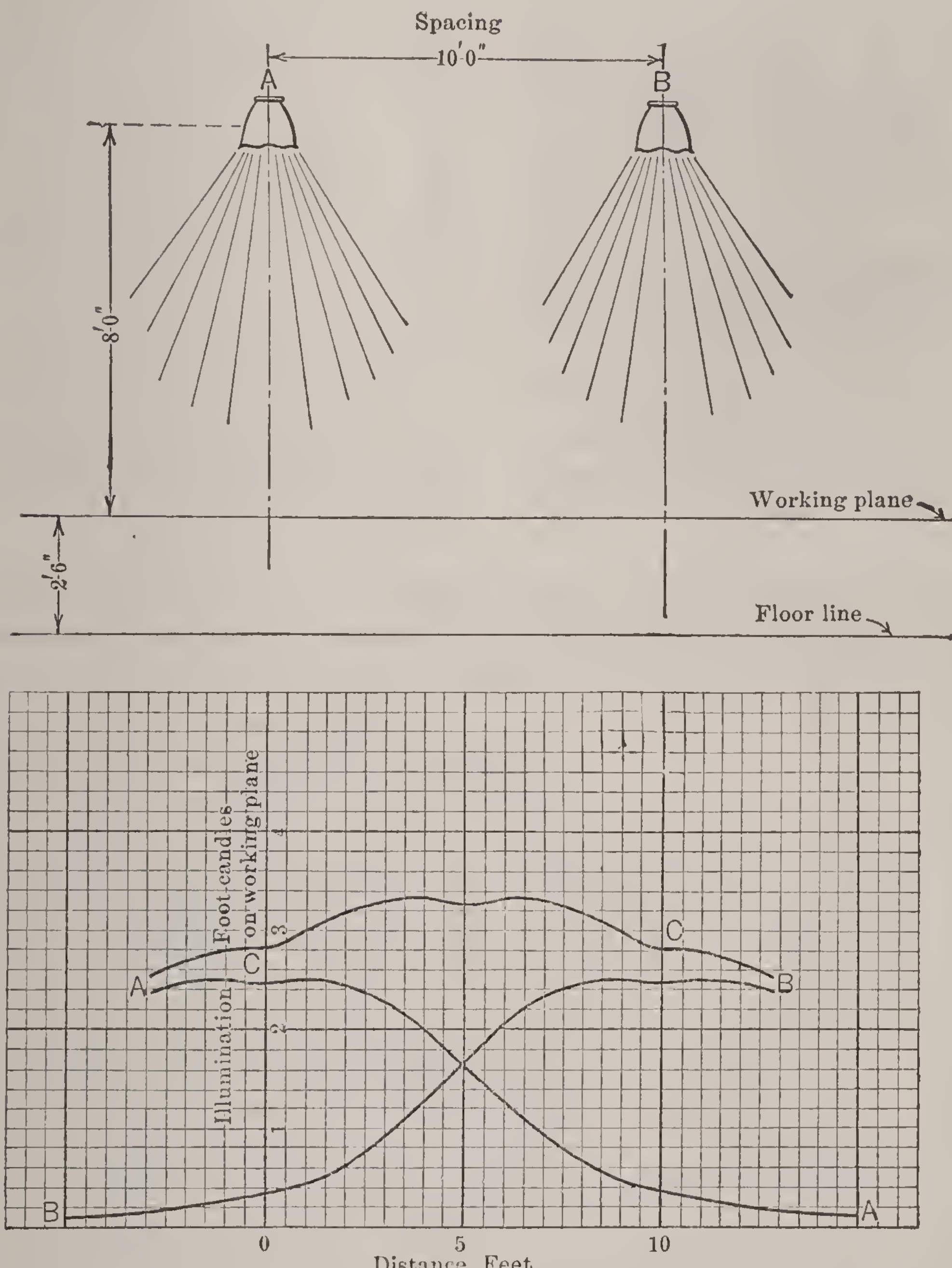


FIG. 47.—Illumination Produced by Two Tungsten Lamps.

(100-watt Mazda B lamps with intensive prismatic reflectors.) Curve *A*. Illumination produced by lamp *A*. Curve *B*. Illumination produced by lamp *B*. Curve *C*. Combined illumination.

sity is likely to exist. If a second lamp of the same size is located 10 ft. away (Fig. 47) the light from the two lamps overlaps and there is less variation in the illumination. There would

now be 2.83 foot-candles directly below either lamp, while 2 ft. from the lamp the intensity is 3.2 foot-candles and at 5 ft. or midway between the lamps it is 3.3 foot-candles. By

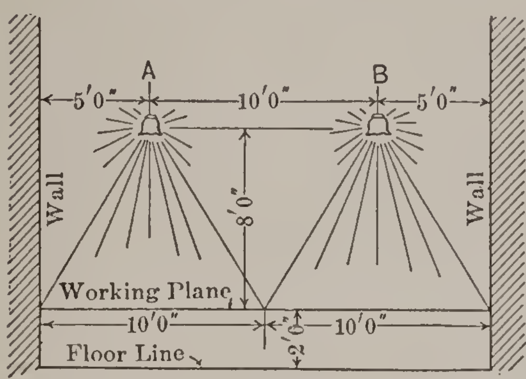


FIG. 48.—Effect of Height upon Uniformity of Illumination.

Lamps arranged with proper height and spacing. Intensive style of reflector.

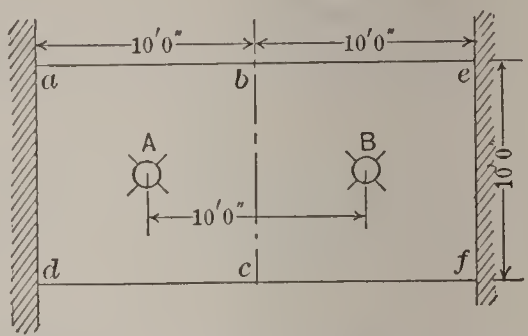


FIG. 49.—Illumination of a Surface by Tungsten Lamps.

This shows a plan view of the lamps in Fig. 48. Most of the light from A falls on square *abcd*, and from B falls on square *befc*. The light overlaps somewhat, as shown in Fig. 47.

using a number of these units, spaced 10 ft. apart and mounted 8 ft. above the working plane, practically uniform illumination could be secured. The light which is reflected from walls and ceiling helps to make the illumination more uniform and increases the intensity considerably. **A change of height** affects the distribution. When the lamps are properly located to give uniform illumination, as shown in Fig. 47, most of the light from a lamp is directed by means of the reflector to the portion of the working surface beneath it. We can consider that each lamp serves principally to illuminate a square directly below the lamp (Figs. 48 and 49), the length of the sides of the square being equal to the distance between lamps (in this case 10 ft.). There is, of course, a certain amount of light coming from lamp B for example which falls upon the square under lamp A. This, however, is only sufficient to increase the

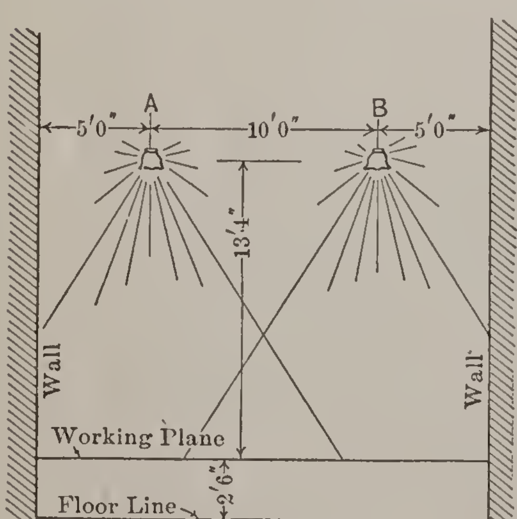


FIG. 50.—Effect of Height upon Uniformity of Illumination.

Lamps arranged with proper spacing but mounted too high. Intensive style of reflector.

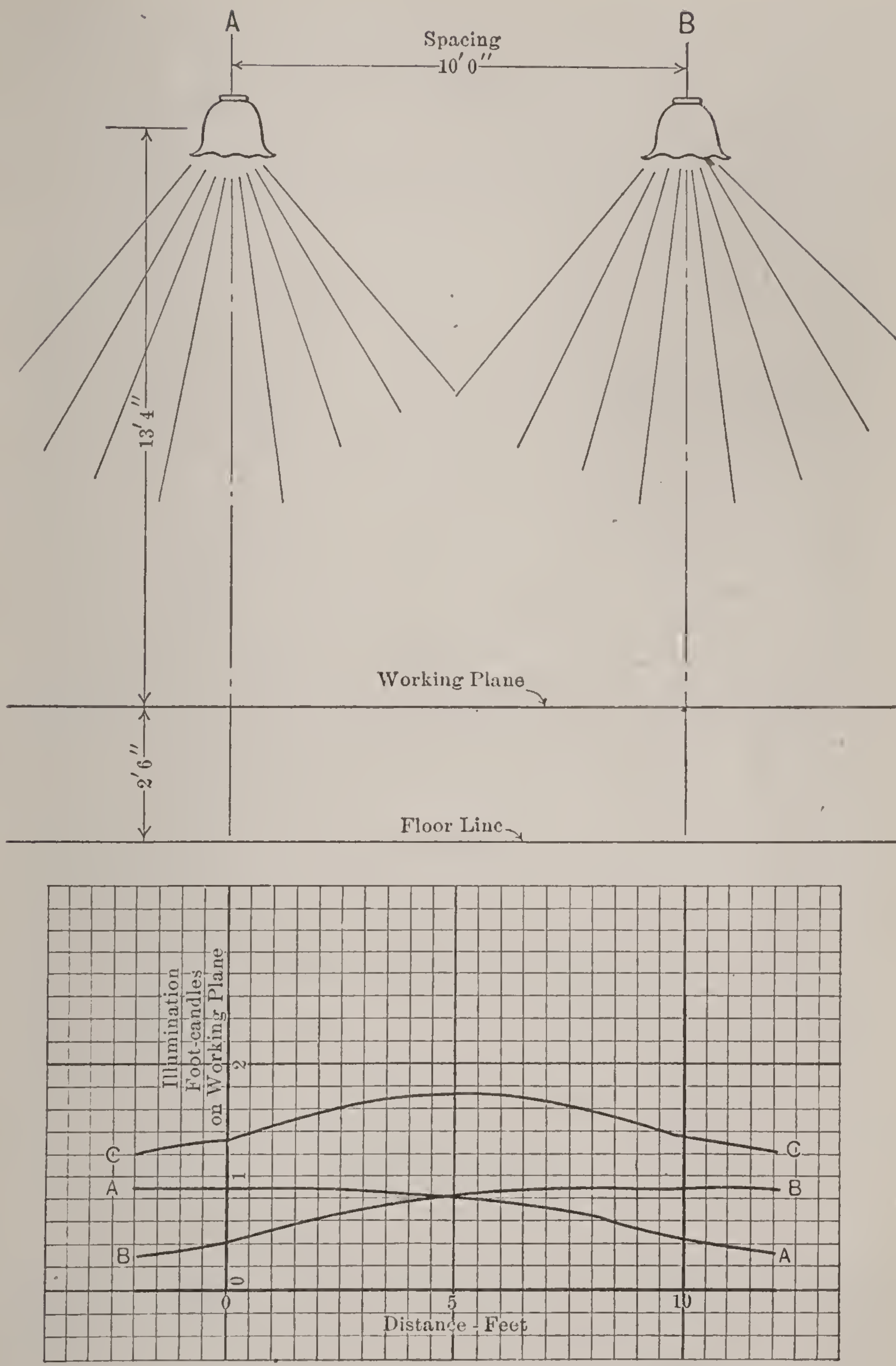


FIG. 51.—Illumination Produced by Lamps Shown in Fig. 50. Height too Great for Spacing.

(100-watt Mazda B lamps with intensive prismatic reflector.)

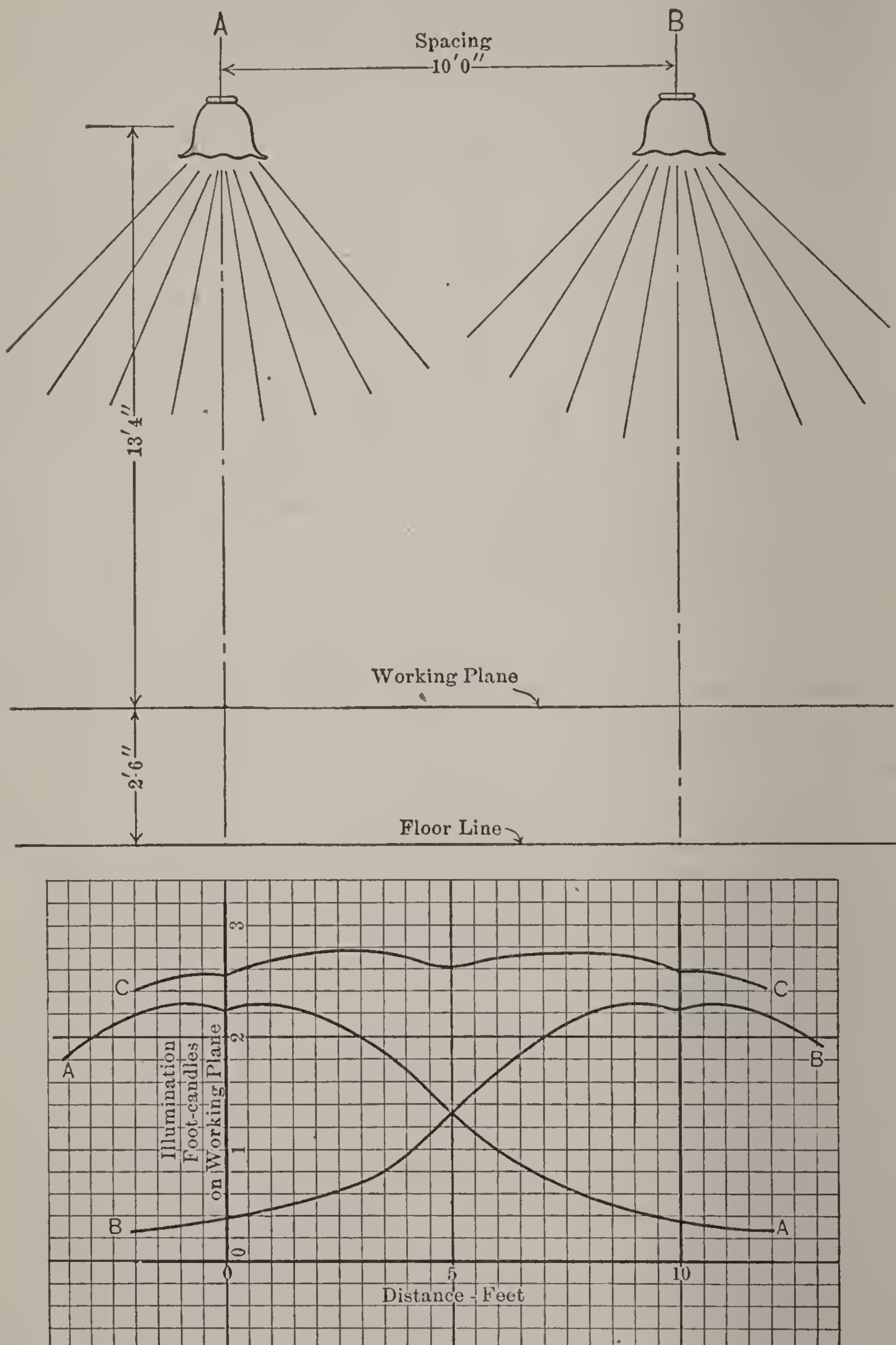


FIG. 52.—Effect of Changing Reflectors.

Spacing and mounting height the same as in Fig. 51, but a more concentrating reflector is used. (100-watt Mazda B lamps with focussing prismatic reflector.)

illumination near the edges of the square under *A* so as to give a uniform illumination. If we use the same lamps and reflectors with the same distance between lamps but increase the height of the unit, we have the condition shown in Fig. 50. Here the light spreads too much and a considerable portion strikes the walls, where much of it is absorbed and lost, or is

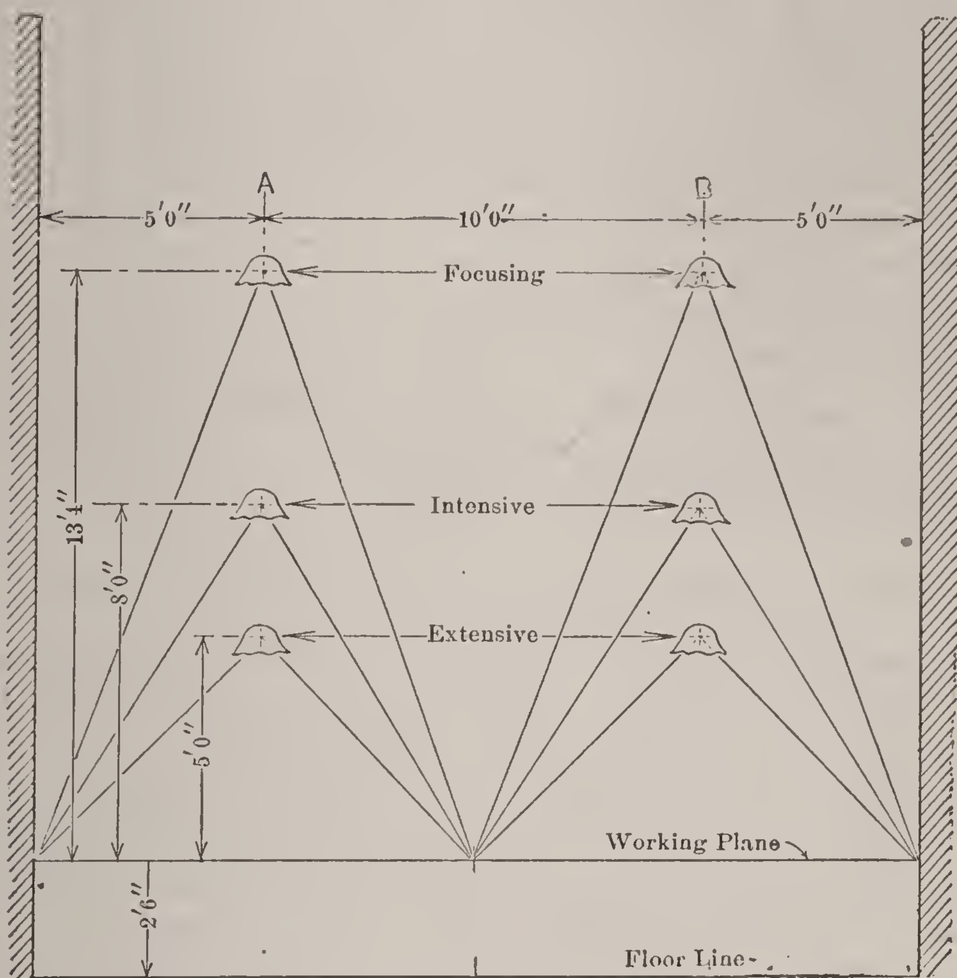


FIG. 53.—Method of Obtaining Uniform Illumination for Different Mounting Heights.

Style of reflector is changed as mounting height is changed. (Holophane Works of G. E. Co.)

reflected away from the working surface so that only a relatively small part is useful. The intensity produced under these conditions is shown in Fig. 51. By using a reflector which concentrates the light more, better results can be obtained. A focussing type reflector using the *same size lamp* gives the intensities shown in Fig. 52. It will be seen that these are nearly equal to the intensities produced when the lamps were

equipped with intensive reflectors and were mounted 8 feet high. The reflection from the walls would tend to equalize this difference and therefore *the height of mounting does not greatly affect the illumination intensity, provided the proper style of reflector is used.* The relation between mounting height, spacing and style of reflector is shown in Fig. 53 for the reflectors made by one manufacturer. Since there usually cannot be very much variation in mounting height in a particular case, different spacings as a rule require different styles of reflectors. The method of selecting a particular reflector for a certain spacing and mounting height is explained in paragraph 128. With indirect and semi-indirect systems there is also a definite relation between the spacing of the units, the height above the floor and the distance below the ceiling, and this must be followed if uniform illumination is to be secured. With arc lamps and mercury-vapor lamps, no attempt is made to change the reflectors to suit different mounting heights. As used, however, a fairly uniform illumination is secured.

(6) Power Required—Uniform Illumination

120. Tungsten Lamps. The area of the room, multiplied by the required intensity in foot-candles, will give the total lumens which must strike the working plane.* The lamps must furnish all of this light and in addition must supply the light which is absorbed by the reflector, walls and ceiling. The amount of light thus absorbed depends upon the kind of reflector used and the color of the walls and ceiling. Even under favorable conditions only 40 to 60 per cent of the total light produced by the lamp finally reaches the working surface. The percentage of the total light which is useful is called the **utilization efficiency** of the lamp. This varies with the kind of reflector used and the color of the walls and ceiling. Values for tungsten lamps are given in Table 10. Dividing the lumens required for the working surface by the utilization efficiency gives the total lumens which the lamps must produce. Dividing the total lumens produced by the lamps by the lumens per watt† for the particular size of lamp used gives the total watts neces-

* Since 1 lumen per square foot will produce an illumination of 1 foot-candle. See Chapter 4.

† Given in tables of lamp ratings.

sary to produce the required intensity. This can be expressed by formulas as follows:

Let A = area of room in square feet;
U = utilization efficiency from Table 10;
I = intensity of illumination in foot-candles;
W = total watts required to produce the intensity I;
L = total lumens which must be produced by the lamps;
l = lumens per watt for the particular lamp used. (See Tables 2 and 3);
w = watts per square foot required to produce the intensity I. Then

$$L = \frac{I \times A}{U} \quad \ldots \quad (1) \qquad I = \frac{L \times U}{A} \quad \ldots \quad (2)$$

$$W = \frac{L}{l} = \frac{I \times A}{l \times U} \quad \ldots \quad (3) \qquad I = \frac{W \times U \times l}{A} \quad \ldots \quad (4)$$

Example 1. Required the power necessary to produce 3 foot-candles uniform illumination in a room having an area of 1000 square feet. Ceilings and walls light. Prismatic reflectors and vacuum type, 100-watt lamps used.

$$\text{Total lumens } (L) = \frac{3 \times 1000}{0.53} = 5670 \text{ lumens,}$$

$$\text{Total watts } (W) = \frac{5670}{10.30} = 550 \text{ watts.}$$

Example 2. Required the power for Example 1 when gas-filled lamps and steel reflectors are used. Ceiling light, walls medium.

$$\text{Total lumens } (L) = \frac{3 \times 1000}{0.46} = 6521 \text{ lumens.}$$

$$\text{Total watts } (W) = \frac{6521}{12.6} = 518 \text{ watts.}$$

Example 3. A room 40 by 20 feet is lighted with 24 vacuum-type tungsten lamps rated at 60 watts and equipped with translucent glass reflectors. The walls are a medium light buff, and the ceilings a very light buff. The lamps are evenly spaced. Calculate the average intensity on the working surface.

$$\text{Total power } (W) = 24 \times 60 = 1440 \text{ watts.}$$

From Table 11, the walls would be classed as "medium" and the ceiling as "light." Hence U from Table 10 is 0.44.

$$\text{The intensity } I = \frac{1440 \times 0.44 \times 9.8}{40 \times 20} = 7.7 \text{ foot-candles.}$$

Example 4. A room 20 by 60 feet is lighted by three 300-watt (110-volt) gas-filled units with prismatic glass reflectors. The walls and ceilings are light. Calculate the intensity. Table 3 shows that each lamp produces 4600 lumens.

$$I = \frac{4600 \times 3 \times 0.60}{20 \times 60} = 6.9 \text{ foot-candles.}$$

It is usually more convenient to determine the watts per square foot required to give a certain intensity. In example (1) this would be $548 \div 1000 = 0.548$ watt. By using values of this kind, the proper size of lamp can be more easily selected.* Using the factors from Table 10, the watts per square foot required to give an intensity of 1 foot-candle can be calculated. These values are given in Table 12, which is based on Mazda B lamps operating at 1.28 watts per m.s.cp. (1.0 watt per m.h.cp.) and producing 9.8 lumens per watt. Referring to Table 2, it will be seen that the lumens per watt vary somewhat with different sizes of lamps. Also if gas-filled lamps are used the values given in Table 12 must be multiplied by 0.64, which is an average value and corresponds to 300- and 400-watt lamps. For larger sizes the factor is somewhat less, and for smaller lamps it is greater. Table 12 can be used, however, to make the first determination, and then, if greater accuracy is required, the intensity can be calculated by means of the formulas given in this paragraph. Extreme accuracy is not required, however, since an allowance of from 10 to 25 per cent must be made for depreciation due to dust. Referring to Tables 10 and 12, it will be noted that the required watts per square foot are affected materially by the color of the walls and ceiling, particularly in the case of indirect systems. To assist in choosing the proper value, a color classification is given in Table 11. This shows the various shades of color corresponding to the designations used in Tables 10 and 12.

Example 5. A room 40 by 20 feet is to be lighted with vacuum-type lamps using steel reflectors and a direct system. The ceiling is white and the walls are a light buff. Calculate the watts per square foot and the total power required to produce a uniform intensity of 4 foot-candles. Referring to Table 11, we find that the walls would be classified as "medium." Using the column for light ceiling and medium walls in Table 12, we find that 0.222 watt per

* The method of doing this is explained in paragraph 123.

square foot is required to produce an intensity of 1 foot-candle. Hence the power required is

$$w = 0.222 \times 4 = 0.888 \text{ watt per square foot.}$$

or

$$W = 0.888 \times 40 \times 20 = 710 \text{ watts.}$$

If gas-filled lamps were used the power would be

$$0.64 \times 0.888 = 0.57 \text{ watt per square foot.}$$

In all these examples no allowance has been made for a decrease of intensity due to dust on the light-units.

In Table 13 is given the **power required** for the usual kinds of lighting service. This table can be employed to avoid the calculations just described, and it is particularly useful for preliminary calculations or for checking the results of a more careful determination. If the conditions of the problem are unusual, the power should be determined by the aid of Tables 8 or 9 and Table 12, as outlined above. Extreme accuracy in these determinations is not required, however, as it is seldom possible to use the exact power calculated, because it is necessary to use standard size units and to space them to conform to the arrangement of windows, girders or columns.

121. Other Lamps. The watts per square foot calculated as described are for uniform illumination with tungsten lamp units evenly spaced over the entire area considered. For **flame-arc and mercury-vapor lamps**, it is necessary to approximate the required power by assuming a value of watts per square foot based upon similar installations. Approximate values for these lamps are given in Tables 14 and 16.

122. Non-uniform Illumination. When **local lighting** is used alone or is combined with general lighting (uniform) the power required for this local lighting must be added to the power required for the uniform lighting. There is no simple method of calculating the required size of lamp to use for this local lighting, and reliance must be placed upon data obtained from installations similar in character. Tables 8 and 9 contain suggestions for the usual requirements. With **localized general lighting**, the power can be calculated only after the number and size of units have been determined. Here, also, the size cannot be easily calculated from the required foot-candles and experience with similar installations is the best guide.

(7) Size of Light Unit

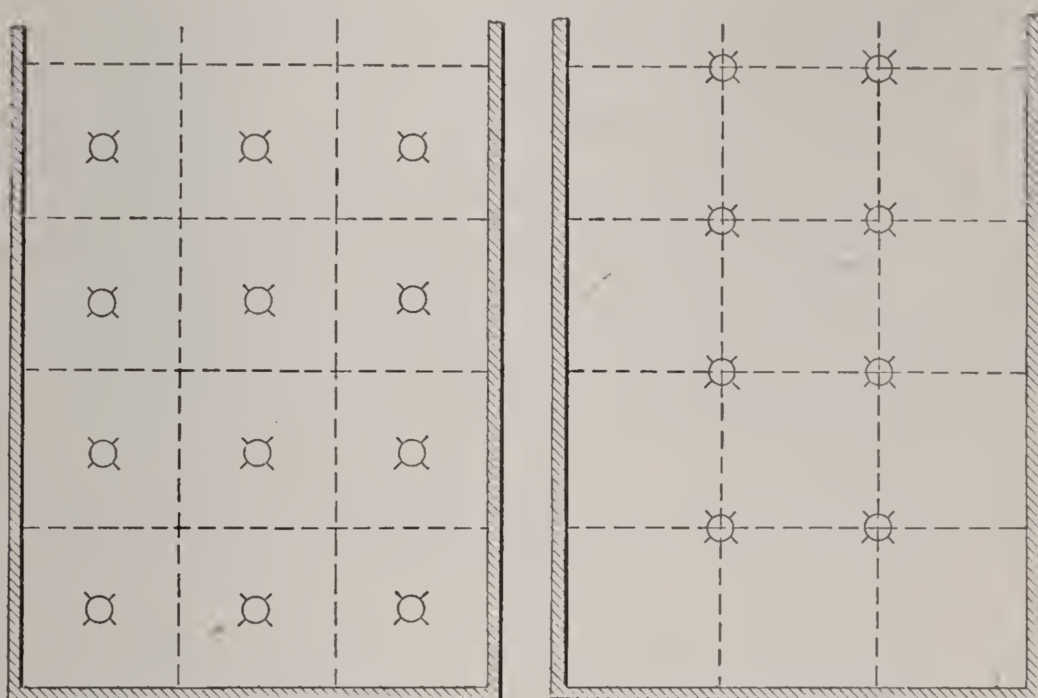
123. General Lighting. With this method of lighting, it is customary to make the units all of the same size, and to so choose the size that the total power will be about equal to the total watts (W) which must be used to produce the required illumination. The size of unit will therefore depend upon the number of units selected. In general, for **direct systems,** it is not satisfactory to employ only one or two units except in very small rooms. The size of the unit which it is best to use depends primarily upon the height of ceiling. For low ceilings, small sizes of units should be used, while for higher ceilings the larger units are most suitable. From this it follows that arc lamps are suitable only for high ceilings where they can be mounted well above the usual line of vision. In Table 15 are given the sizes of lamps best suited for various ceiling heights. The exact size chosen will be settled when the spacing and power requirements are finally determined, but the size used should be checked by comparison with this table. For **indirect and semi-indirect** systems, the size is chosen from a knowledge of the required spacing, as will be explained in paragraph 125.

124. Non-uniform Lighting. For local lighting the size of tungsten lamp used would depend upon the intensity of illumination desired. In general, however, a 50-watt lamp would be the largest size required, and in many cases, as for example in lighting sewing machines, a much smaller size may be used. For **group lighting**, the size would depend upon the height of ceiling, the same as for uniform illumination.

(8) Location of Light Units

125. The spacing of units depends principally upon the extent to which shadows must be eliminated and a good diffusion of the light secured. This is particularly true of direct systems. A wide spacing, besides making the illumination less uniform, also gives stronger shadows and requires the use of larger units. A very close spacing, while giving a more uniform illumination and eliminating shadows to a considerable extent, results in a more expensive installation, so that a balance must be reached by considering the requirements of each class of installation.

It is apparent that a closer spacing would be required in a drafting room, where shadows should be practically eliminated, than in a factory where rough manufacturing is carried on. Tables 17 and 18 give **desirable spacings** for various classes of service for direct and indirect systems. For high ceilings wide spacings and large units are used. The tables give maximum distances and these should not in general be exceeded. It is also best not to use the widest spacing with the lower ceiling height. These tables apply to general lighting with uniformly spaced units.



a—Correct Method. *b*—Incorrect Method.

FIG. 54.—Method of Locating Light Units for Uniform Illumination.

The total area to be lighted may be divided into squares (or rectangles which are nearly square) with a light unit located at the centre of each rectangle. The length of the sides of the rectangle is the spacing of the units. Fig. 54*a* shows the correct way in which to locate the units. They should not be located at the corners of the squares as shown in Fig. 54*b*, because this places the outside rows too far away from the walls. The size of the rectangle which should be illuminated by one lamp depends upon the height at which the lamp can be mounted. This is of course affected by the height of the ceiling. If an attempt is made to use a large spacing with a low ceiling the light rays must be thrown out at wide angles and it is difficult

to secure uniform illumination. On the other hand, if a very small spacing is used, the cost of the installation will be too high. In general, therefore, close spacing and small-size units should be used for low ceilings and large-size units and wide spacing should be used for high ceilings where the lamps can be mounted at a considerable distance above the floor. The exact spacing and hence the size of the rectangle is fixed as soon as the watts per square foot and the most desirable size of unit are settled upon. Thus, if we require 0.5 watt per square foot to give the required intensity and after reference to Table 15 we decide that 100-watt units should be used, the number of units must be so chosen that there will be one for every 200 sq.ft. of area. Hence we can consider that each lamp illuminates a square which is $\sqrt{200} = 14.13$ ft. on a side. The lamps should therefore be spaced 14.13 ft. apart and located at the centres of the squares as indicated in Fig. 54*a*. If 60-watt lamps were used each lamp could illuminate only $60 \div 0.5 = 120$ sq.ft. and the lamps must be spaced $\sqrt{120} = 10.95$ ft. apart. To assist in determining the required spacing for various sizes of units, Fig. 55 is used.

Example 1. Required the spacing to allow 1.0 watt per square foot in an office.

From Fig. 55 we have:

For 25 watt-units..................	5.0-foot spacing
40	6.4
60	7.8
100	10.0

The spacing chosen must suit the requirements of Table 15, and should check with the values given in Tables 17 and 18. Thus, for a 14-ft. ceiling 100- or 150-watt units are desirable. Table 17 indicates that for direct systems the spacing should be from 9 to 14 ft. for ceilings 12 to 16 ft. high. Hence a 100-watt lamp with a spacing of 10 ft. would be satisfactory. If 150-watt units are used, the spacing should be 12.2 ft., which would be undesirable from the standpoint of shadows. If 60-watt units are used, the spacing should be 7.8 ft., which is too close for an economical installation.

The chart (Fig. 55) can of course be used for all styles of lamps, both arc and incandescent, *provided the required watts per square foot are calculated for the particular type of lamp used.*

Example 2. Find the spacing for gas-filled lamps to give the same illumination as in Example 1. This would require 0.64 watt

per square foot instead of 1.0 watt required for vacuum lamps. From Fig. 55 we have:

For 100 watt units	....	12.6 ft. spacing
75	....	10.8

The 75-watt size could therefore be used instead of the 100-watt vacuum lamp.

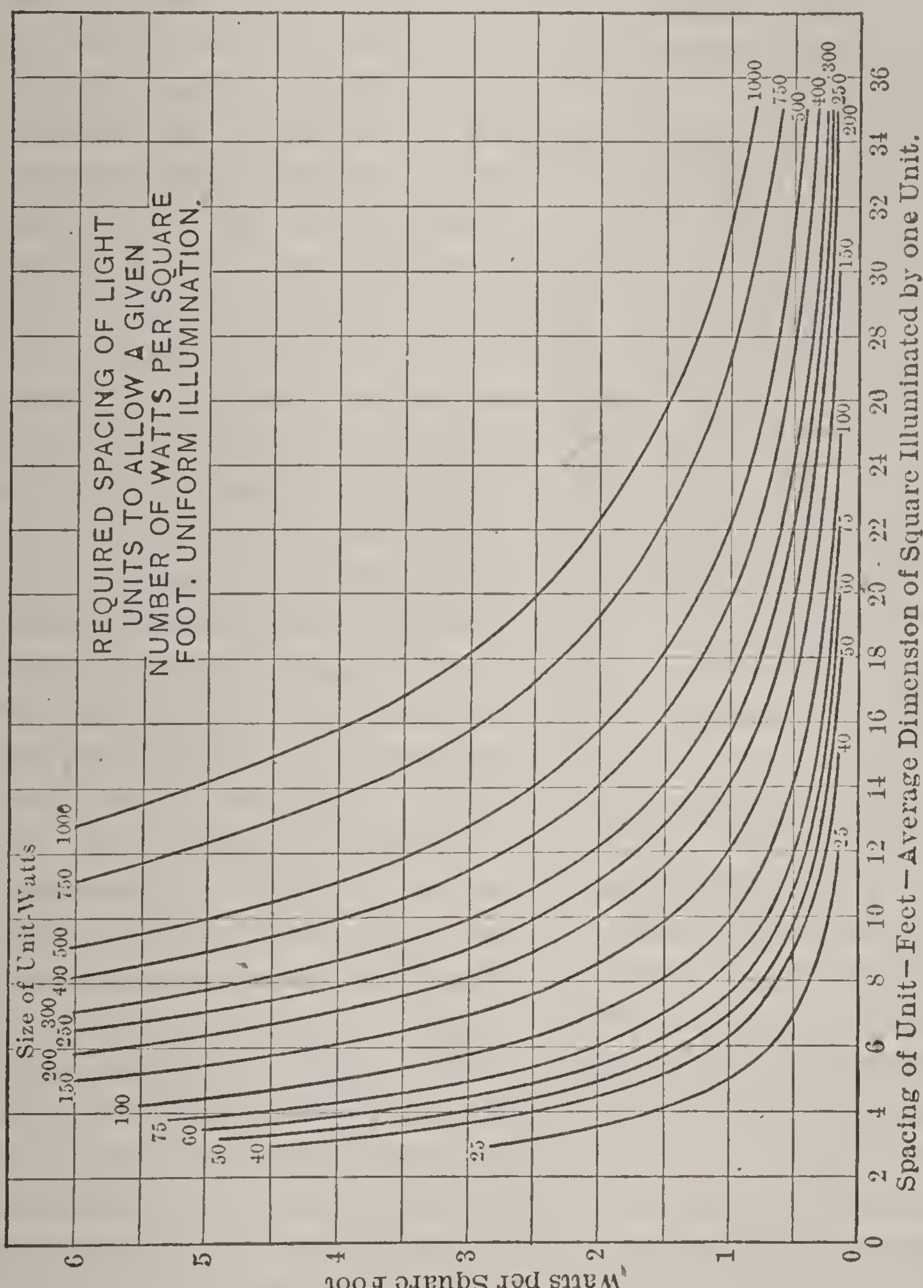


FIG. 55.—Spacing Chart.

126. Arrangement of Units. When the desirable spacing has been determined, as explained in the previous paragraph, the arrangement can be settled upon. To give **uniform illumination,** the units should all be of the same size and should be

located in regular rows about as shown in Fig. 54*a*. If there are no columns in the room and the ceiling is not divided into bays by beams or girders, the arrangement shown in Fig. 59 may be used. The lamps should be located in parallel rows with the spacing between rows and between lamps in the same row as nearly as possible equal to the value obtained from Fig. 55. The distance between the walls and the nearest row should be one-half the distance between the other rows, unless benches are located along the wall, when the first row should be about 12 to 18 in. nearer the wall than the edge of the bench. Sometimes a **staggered arrangement** of lamps (Fig. 56) is used. This may be necessary to obtain the required illumination with the sizes of lamps available. In general, however, such an arrangement should be avoided, because of the irregular appearance of the lamps. When there is a line of columns running the length of the room or where the ceiling is divided into bays by means of deep girders or beams, each bay should be considered separately and the lights so spaced as to avoid troublesome shadows. The arrangement in this case is shown in Fig. 58. The line of columns divides the room into sections and the units are located symmetrically with this row of columns. The beams, on a line with the columns divide the ceiling into bays (in this case 15 by 23 ft.), and the lamps must be located symmetrically in each of these bays in order to produce a good appearance. Where **group lighting** is employed, the units are so located as to give the proper intensity upon the machine. This would result in different spacings of the units, but usually they may be located in straight rows running the long way of the room, and this is desirable where possible, because of the appearance.

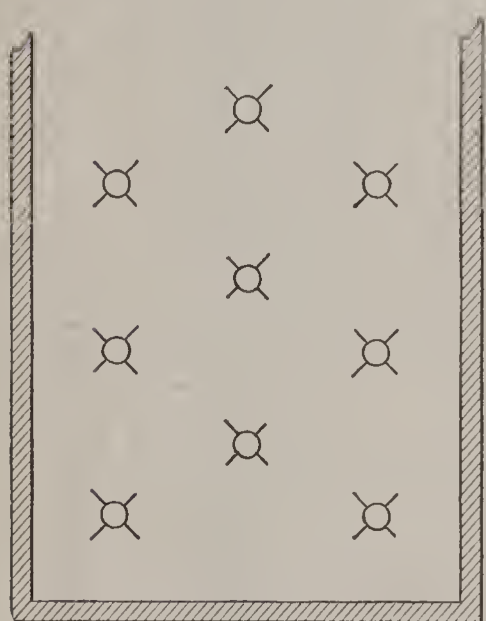


FIG. 56.—Staggered Arrangement of Light Units.

127. Mounting Height. The height at which the unit should be mounted depends upon the system used. Where **general**

lighting is to be provided, the units must be mounted high enough to be out of the range of vision to avoid glare.* In general, the lamps should be at least 8 ft. above the floor and higher if possible. For ceilings from 11 to 16 ft. high the lamps should be about 10 ft. above the floor. For higher ceilings, cranes or other obstructions usually fix the minimum mounting height. If deep girders divide the ceiling into bays, the lamps should be located slightly below the bottom edge of the girders if possible. It might be considered that the height of the lamp above the floor would have an important effect upon the intensity of illumination which would be secured by the lamp, and this would be the case (according to the inverse square law)† if no reflectors were used. When, however, we use a reflector which directs the light in the proper direction, we can secure practically the same amount of light upon the working surface *regardless of the height of the units.* This is shown in Fig. 53. Accordingly, if we change the style of reflector when the mounting height changes, we can obtain the same illumination with the same expenditure of power. In other words, the values of watts per square foot required to produce a certain intensity as given in Table 12 can be used without correcting for different mounting heights. For **group lighting,** the same rules apply as regards the mounting height. For **local lighting** the units are mounted as close to the work as possible. With **semi-indirect or indirect systems,** the desirable spacings are given in Table 18, together with the hanging height of the fixture, or the distance between the fixture and the ceiling. With direct units, this distance is not important, but for the other systems it is necessary to choose a suitable hanging height in order to properly distribute the light reflected from the ceiling. The hanging height varies somewhat with different makes of fixtures, but the values given are representative of the ordinary units.

Example 1. An office having a 12-ft. ceiling is to be provided with direct lighting and no desk lamps. Hence from Table 17 a mounting height of 9 to 12 ft. would be used with a spacing of 7 to 11 ft. In this case, a spacing of about 10 ft. with a mounting height of 9 or 10 ft. would be satisfactory.

Example 2. For an indirect system, Table 18 indicates that for a 12-ft. ceiling the spacing should not exceed 18 ft. and the distance from the ceiling to the fixture should be from 2.5 to 3.0 ft.

* See paragraph 74. † See paragraph 66.

(9) Selecting Reflector or Globe

128. The general type of reflector, whether glass or metal, must be settled before the power required for illumination can be calculated as explained in paragraph 120. After the size of the unit has been selected, the proper size and shape of reflector can be chosen to suit the particular lamp employed. Usually **reflectors for direct lighting** are suitable for use with only one or two sizes of tungsten lamps. The shape of the reflector, which determines the distribution of light, must be selected with proper regard to the arrangement of the units. It has already been pointed out* that if uniform illumination is to be secured, the style of reflector selected will depend upon the mounting height and spacing of the units. Thus wide spacing and low mounting height require a reflector giving an extensive distribution, while for closer spacings an intensive or a focussing distribution is required. Fig. 57 shows these relations for various reflectors used for direct lighting. The curves indicate the style of reflector required to give uniform illumination on the working plane, which is assumed to be 2.5 ft. above the floor; but the mounting height is specified from the floor. If the work is at a different level than the one assumed, proper allowance must be made for the difference.

Example 1. For reflectors spaced 10 ft. apart the following styles should be used:

Extensive for a height above the floor of about 7 ft. 6 in.
Intensive for a height above the floor of about 10 ft.
Focussing for a height above the floor of about 13 ft.
Focussing for a height above the floor of about 16 ft.

Example 2. If the reflectors must be mounted about 15 ft. above the floor, the following styles should be used:

Extensive for a spacing of about 25 ft.
Intensive for a spacing of about 15 ft.
Focussing for a spacing of about 10 ft.

Besides choosing the proper size of reflector for the lamp used and the proper shape to give the desired distribution of light for the spacing and mounting height, it is also necessary to choose the proper style of shade holder so as to centre the lamp

* See paragraph 119.

in the reflector. If this is not done, the distribution of light will not be as designed, and uniform illumination will not be

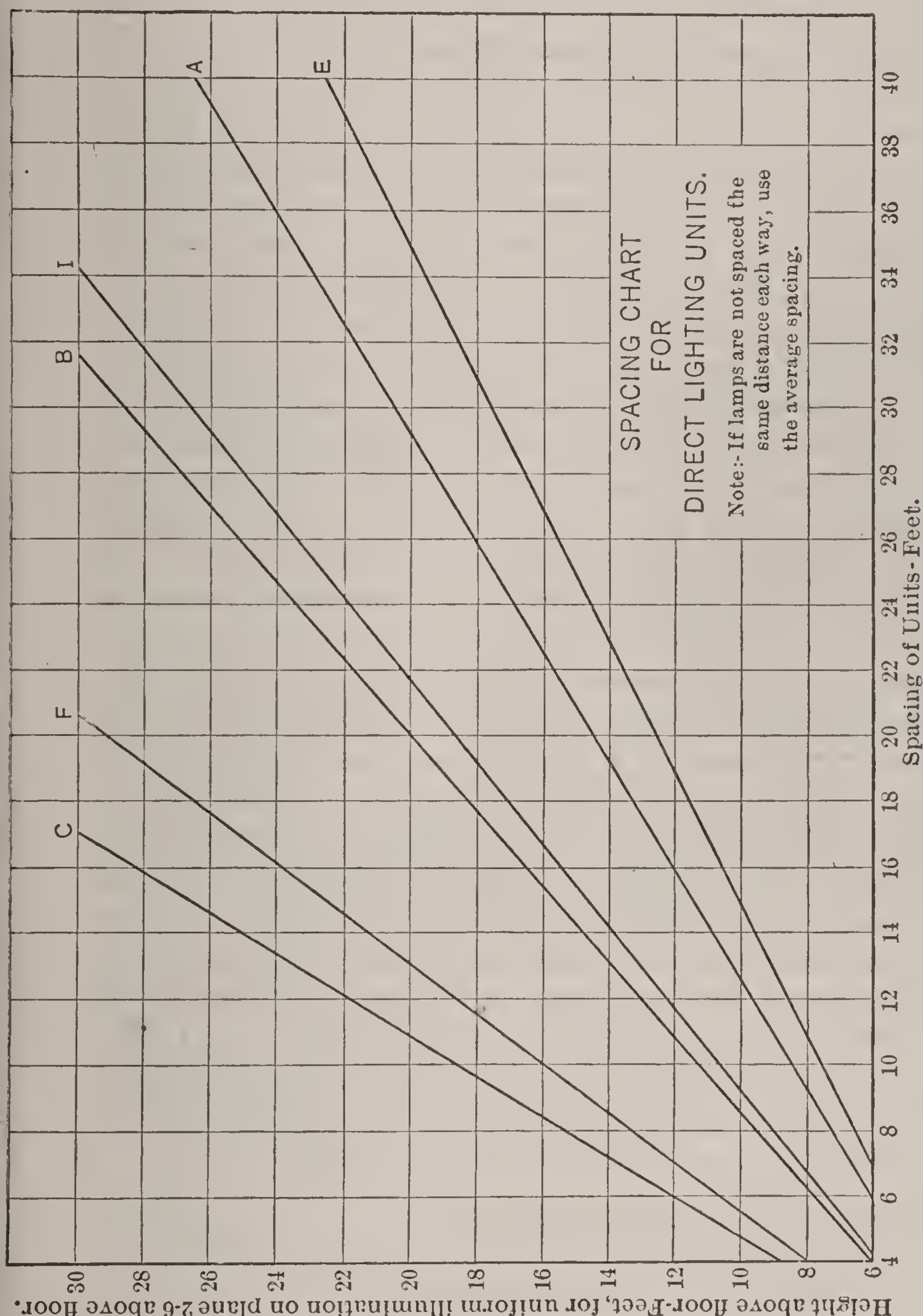


FIG. 57.—Spacing Chart for Direct Lighting Units.

Curve *A*. Mirror (X-Ray) type, distributing style. Curve *B*. Mirror (X-Ray) type, semi-concentrating style. Curve *C*. Mirror (X-Ray) type, concentrating style. Curve *E*. Prismatic and steel types, extensive style, or prismatic enclosing globes. Curve *F*. Prismatic and steel types, focusing style. Curve *I*. Prismatic and steel types, intensive style, or deep-bowl translucent glass types.

NOTE. When a reflector is required for a spacing between two lines, use the more concentrating. For example, if spacing requires a reflector between *E* and *I*, use *I*, etc. Distributing styles of steel and glass reflectors are used on spacings wider than *E*.

secured. **For indirect and semi-indirect systems,** the size of bowl used would depend principally upon the ceiling height, which would fix the size of unit in accordance with Table 15.

Examples

129. Office. Size 46 by 45 ft. with a 14-ft. ceiling. The columns and girders form six bays, each 15 by 23 ft. The lighting would be classed as commercial and good diffusion and pleasing appearance are essential. For these reasons a semi-indirect system will be used. Tungsten lamps would of course be employed. Referring to Table 8, it will be seen that large offices require from 4 to 8 foot-candles when no desk lamps are used. Because the conditions are average we will assume 6 foot-candles. Allowing 20 per cent depreciation due to dust, because semi-indirect bowls gather dust faster than direct systems, the intensity with clean units should be $1.20 \times 6 = 7.2$ foot-candles. The ceilings are ivory white and the walls a very light buff, so both would be classed as "light." (Table 11.) Table 12 shows that for vacuum-type lamps, 0.291 watt per square foot is required to produce 1 foot-candle. The required power is then $0.291 \times 7.2 = 2.09$ watts per square foot. The area of the room is $46 \times 45 = 2070$ sq.ft. Since the values in Tables 10 and 12 are based on areas of 200 to 1000 sq.ft., the power required would be somewhat less than the value calculated. With light walls, however, it is not well to make any change. Since the room is divided into bays 15 by 23 ft., we could have one, two, or four lamps per bay. Referring to Table 18, it will be seen that for a 14-ft. ceiling the spacing should not exceed 24 ft. If we used one lamp per bay, the spacing would be 23 by 15 ft. While this might be used, the considerable difference between the lengths of the two sides of the rectangle illuminated by one lamp would make it preferable to use two units per bay, giving a spacing of 15 by 11.5 ft. The average spacing is then 13.25 ft. Reference to Fig. 55 indicates that about 360 watts per unit are required. If we used three 100-watt lamps per unit, we would have:

$$W = 3 \times 2 \times 6 \times 100 = 3600 \text{ watts},$$

$$w = \frac{3600}{2070} = 1.74 \text{ watts per square foot},$$

which is somewhat less than required. The intensity can be calculated from formula (4):

$$I = \frac{3600 \times 0.35 \times 10.30}{2070} = 6.3 \text{ foot-candles}.$$

This is slightly low. If four 100-watt lamps were used, we would have 4800 watts total or 2.32 watts per square foot, and this would give an intensity:

$$I = \frac{4800 \times 0.35 \times 10.30}{2070} = 8.37 \text{ foot-candles.}$$

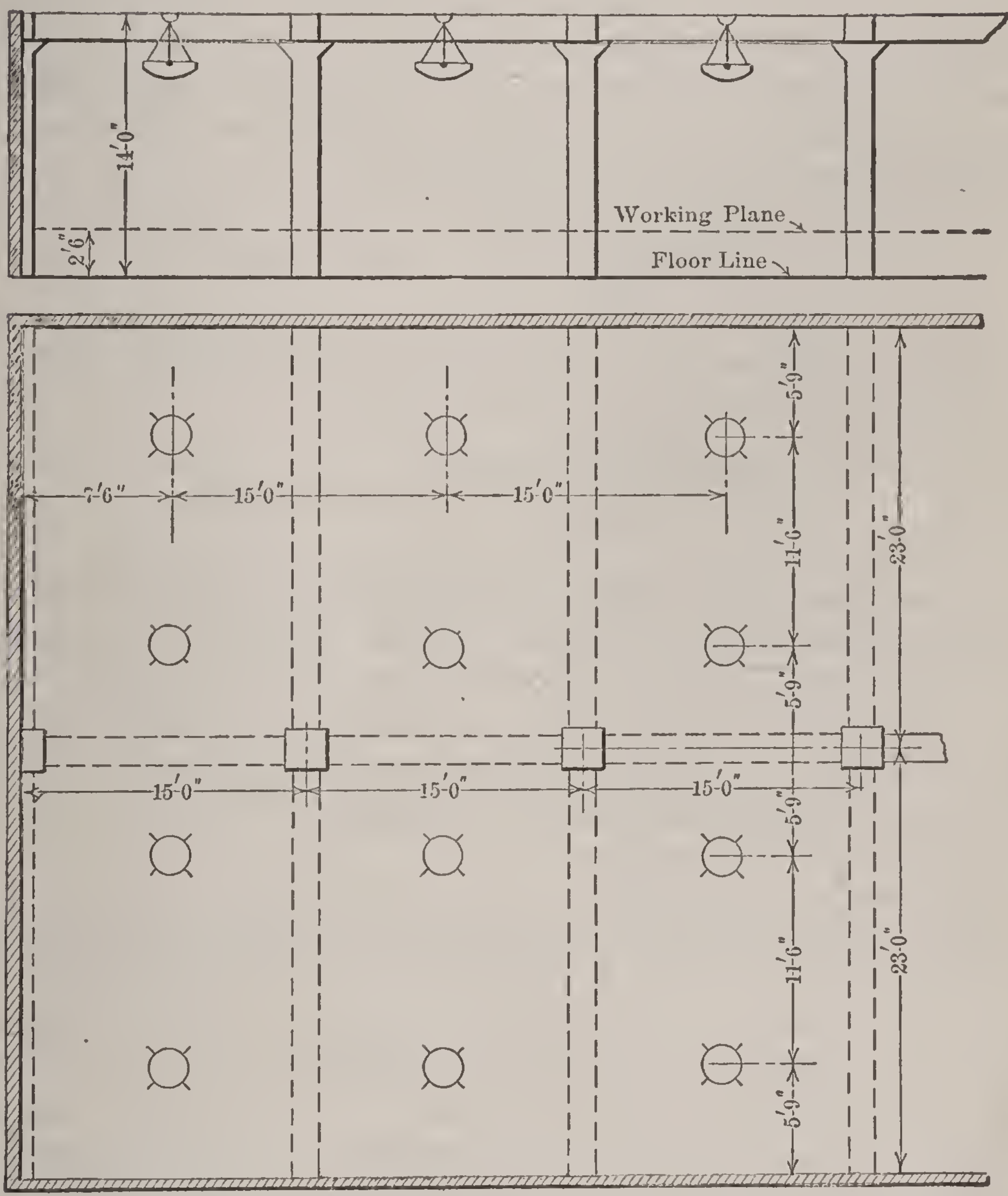


FIG. 58.—Lighting Plan for an Office.

This is about 16 per cent too high, but in general this value would be chosen rather than the lower value in order to be on the safe side. The arrangement of units is shown in Fig. 58. According to Table 18, the hanging height should be from

3.5 to 4 ft. In this case, since the spacing is considerably less than the maximum, a height of 3.5 ft. would give the best appearance. The lamps would be mounted horizontally inside a suitable bowl. If gas-filled lamps are used, the power would be $0.291 \times 0.64 = 0.186$ watts per square foot. To produce 7.2 foot-candles, the power is $0.186 \times 7.2 = 1.34$ watts per square foot. Two units per bay would be used as before, giving an average spacing of 13.25 ft. From Fig. 55 we find that about 240 watts per unit are required. The nearest standard size is 200 watts, which gives a total of 2400 watts or 1.16 watts per square foot. The intensity is

$$I = \frac{2400 \times 0.35 \times 14}{2070} = 5.7 \text{ foot-candles.}$$

If 300-watt lamps are used, the total power is 3600 watts, giving 1.74 watts per square foot and an intensity

$$I = \frac{3600 \times 0.35 \times 15.3}{2070} = 9.3 \text{ foot-candles.}$$

It is apparent that neither of these sizes fits the case exactly. If it is assumed that the lamps will be cleaned very frequently and the character of the work is not too exacting, 200-watt lamps would be satisfactory. If there is a chance of dust accumulating, the 300-watt lamps would be better. A single lamp would be used in each unit because gas-filled lamps operate better in a vertical position.

130. Store. Dimensions: 25 ft. wide, 60 ft. long, 13-ft. ceiling. Dry goods store displaying both light and dark goods. The walls are covered with shelves and therefore should be classed as "dark." The ceiling is "light." General illumination by the direct system will be employed, to reduce the first cost of installation as much as possible. Vacuum-type tungsten lamps with velvet finished, prismatic reflectors are suitable. Since the store is located in a small city, a moderate intensity is satisfactory. Table 8 indicates that from 4 to 7 foot-candles are required. For this store, 4 foot-candles would be satisfactory. Allowing 10 per cent for depreciation, we should start with $1.10 \times 4 = 4.4$ foot-candles. The power required to produce 1 foot-candle is 0.227 watt per square foot (Table 12). The required power is $0.227 \times 4.4 = 1.0$ watt per square foot.

The total area is $60 \times 25 = 1500$ square feet. Table 17 indicates that the desirable spacing for stores with ceilings 11 to 15 ft. high is 10 to 16 ft. If one row of lamps is used, it would not be possible to get good lighting on the counters. With two rows, the spacing between rows would be 12.5 ft. With 5 lamps per row the spacing the other way would be 12 ft. Fig. 55 indicates that for 1 watt per square foot 150 watt units must be used. These are not made for 110-volt service (see Table 2). If 6 lamps are used per row, the spacing becomes 10 by 12.5 ft., an average of 11.25 ft. To give 1 watt per square foot would require (Fig. 55) about 125 watts per unit. Using 100-watt lamps would give 1200 watts total power or 0.8 watt per square foot. The intensity would be

$$I = \frac{1200 \times 0.45 \times 10.30}{1500} = 3.7 \text{ foot-candles.}$$

This is too low. **With gas-filled lamps** and the same kind of reflectors, the power to produce 1 foot-candle is $0.213 \times 0.64 = 0.136$ watt per square foot or $0.136 \times 4.4 = 0.6$ watt per square foot to produce 4.4 foot-candles. With 5 lamps per row, giving a spacing of 12.5 by 12 ft., a 100-watt unit could be used. This gives 1000 watts total or 0.67 watt per square foot. The intensity is

$$I = \frac{1000 \times 0.48 \times 12.6}{1500} = 4.0 \text{ foot-candles,}$$

slightly low. Using 6 lamps per row gives 1200 watts total, 0.8 watt per square foot and an intensity

$$I = \frac{1200 \times 0.48 \times 12.6}{1500} = 4.8 \text{ foot-candles.}$$

While this is slightly high, it is a better value than the other, as it allows more for depreciation due to dust. Since the area is somewhat more than 1000 sq.ft., according to the note under Table 10, the factor 0.48 might be increased somewhat. This applies to rooms which are nearly square, in which case the light from other bays helps to raise the illumination in the central portion of the room. For long, narrow rooms, such as we have here, it would not be safe to increase this quantity. The arrange-

ment is shown in Fig. 59. The units should be mounted as high as possible because of their brightness. Assuming a height of 12 ft. above the floor, Fig. 57 shows that for an average spacing of 11.25 ft. intensive reflectors should be used.

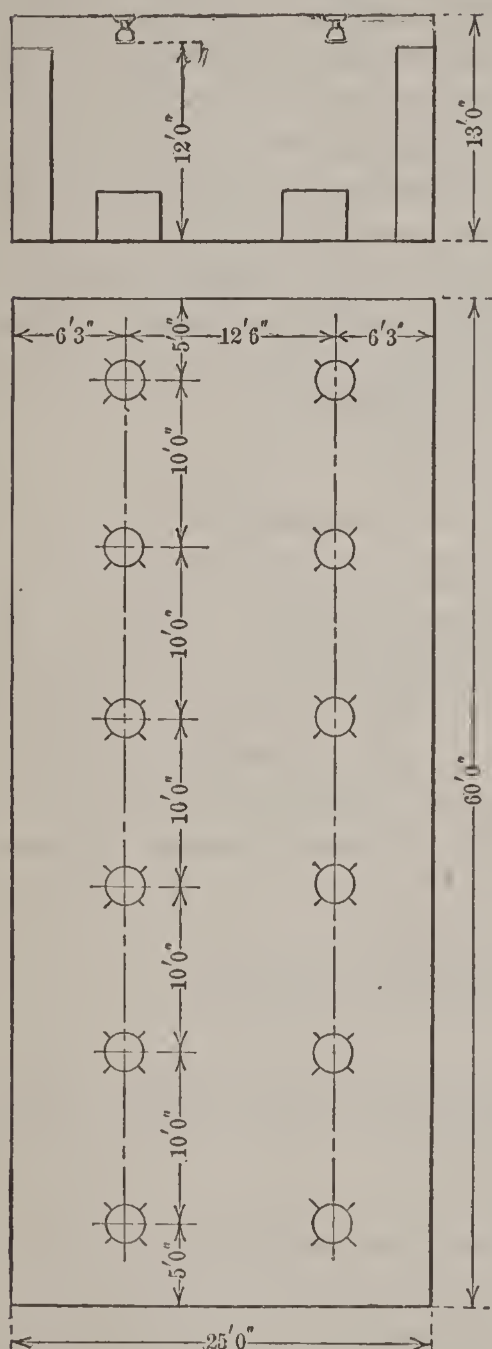


FIG. 59.—Lighting Plan for a Store.

131. Machine Shop. The shop is 128 ft. long by 44 ft. wide and is divided into 16 bays each 16 by 22 ft. The ceiling is 14 ft. high. Floor area $44 \times 128 = 5632$ sq.ft. Rather close work is carried on. Direct lighting with tungsten lamps, using steel reflectors, is most suitable. From Table 9, we find that for machine tools and fine work from 5 to 8 foot-candles are required. Assume 6 and allow 25 per cent for dust. The intensity with clean lamps should be $1.25 \times 6 = 7.5$ foot-candles. The ceiling is a very light buff and the walls a medium light buff. Hence the classification is "light" and "medium" (Table 11). From Table 12, for vacuum-type lamps 0.222 watt per square foot is required for 1 foot-candle, or $7.5 \times 0.222 = 1.68$ watts per square foot for the required illumination. Either one, two or four units could be used in each bay. With four units the average spacing is 9.5 ft. and 150-watt units would be required (Fig. 55). Vacuum-type lamps are not commonly used in this size. **With gas-filled lamps** the watts per square foot would become $0.222 \times 0.64 = 0.142$ watt per square foot for 1 foot-candle or $7.5 \times 0.142 = 1.07$ watts per square foot for

the required illumination. With one unit per bay, the spacing would be 16 by 22 ft. and 400-watt units would be required. With two per bay, the spacing is 16 by 11 ft. and 200-watt units are necessary. With 4 per bay, 100-watt units with a spacing of 8 by 11 ft. would be required. Table 17 indicates that

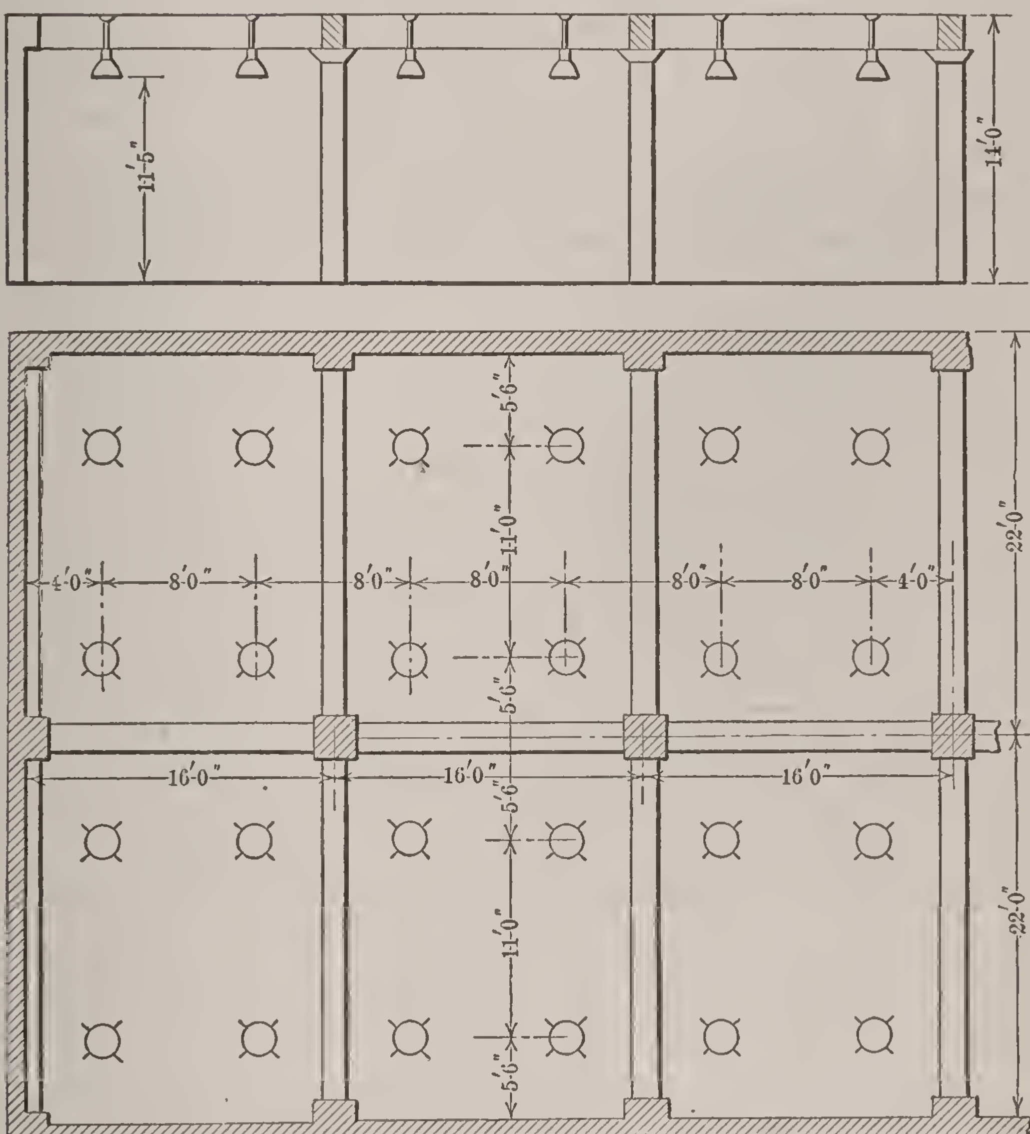


FIG. 60.—Lighting Plan for a Machine Shop.

for close work for ceilings 11 to 15 ft. high, spacings of 8 to 13 ft. should be used. Four 100-watt units would therefore give the best arrangement. The total power would be $4 \times 16 \times 100 = 6400$ watts, giving 1.14 watts per square foot. The intensity would be

$$I = \frac{6400 \times 0.46 \times 12.6}{5632} = 6.6 \text{ foot-candles.}$$

This is lower than the required value of 7.5 foot-candles. Since this is a large room the utilization efficiency would be somewhat higher than 0.46. (See note for Table 10.) We have already made allowance for dust, and therefore, unless there were many obstructions such as belts or pipes, the illumination would be sufficient. The arrangement is shown in Fig. 60. The working plane in this case would be more than 30 in. above the floor and can be assumed as 4 ft. Hence the mounting height should be 18 in. more than the value given in Fig. 57. If an intensive style of reflector is used with an average spacing of 9.5 ft. it should be mounted $10+1.5=11.5$ ft. above the floor in this case. Enamel steel reflectors would be the best kind to use.

CHAPTER 8

OUTDOOR LIGHTING

Street Lighting

132. Street lighting is employed to aid traffic movements, to assist in policing the streets and in some cases to illuminate building exteriors and attract trade.

133. Systems Used. As a rule, street lighting is furnished by the **series system** because the cost of circuits is less.* Alternating current is generally used. Direct current is necessary where metallic-electrode arc lamps are used. For a.c. circuits, 6.6, and 7.5 and sometimes 10 amperes are used; for d.c., 4.5 and 6.6 amperes are standard. The voltages for series circuits are high. With **arc circuits** 50 or 75 lamps are frequently operated on a single circuit. Allowing 84 volts per lamp,† the total voltage becomes 6300. Series incandescent circuits are somewhat lower in voltage. The power factor of a metallic-electrode arc-lighting system, including the regulating transformer, is about 0.65. For incandescent-lamp systems, with regulating transformers, it is about 0.83. At the present time, series circuits are almost always supplied from a constant-potential, a.c. source. Arc-light generators are seldom used. The common arrangement is a constant-current transformer, which keeps the current in the circuits constant regardless of the number of lamps in circuit. These transformers are built for different numbers of lamps, and as a rule operate a single circuit. In the larger capacities up to 100 lights, two circuits are supplied from a single transformer. When direct current must be supplied, a Cooper Hewitt mercury-arc rectifier is connected to the constant-current side of the regulating transformer. For **tungsten lighting circuits,** regulating transformers are used in many cases. Another arrangement is the

* See paragraph 212.

† Including a line drop of 4 volts per lamp.

adjuster-socket system (Fig. 61). A transformer is provided to insulate the series circuit from the supply feeder, and taps are employed to allow adjustment for different numbers of lamps. In general, the adjuster-socket system is best for small or medium-size systems. One advantage of this system is that the transformer requires no attention and can be mounted on a pole. A **constant-potential system** is sometimes used for street lighting in the sections of large cities which have Edison mains. The lamps, either arc or incandescent, are turned on by hand at each pole, or are controlled by time switches.

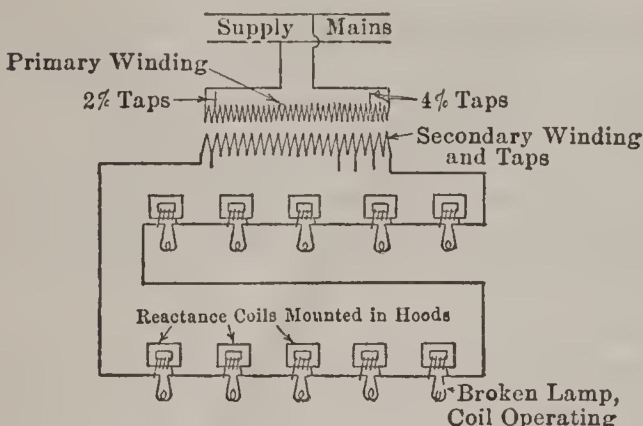


FIG. 61.—Diagram of Adjuster-socket, Series System.

134. Lighting Units.* For **arc-lighting systems**, the metallic-electrode lamp is standard. Flame-arc lamps are used to some extent. Enclosed and open arcs are obsolete and are being rapidly discarded. For **incandescent-lighting systems**, gas-filled tungsten lamps are generally used. They are made in various sizes† to suit the different capacity circuits and are frequently installed in the same circuit with arc lamps. There seems to be a tendency, at present, to replace arc lamps with tungsten lamps,

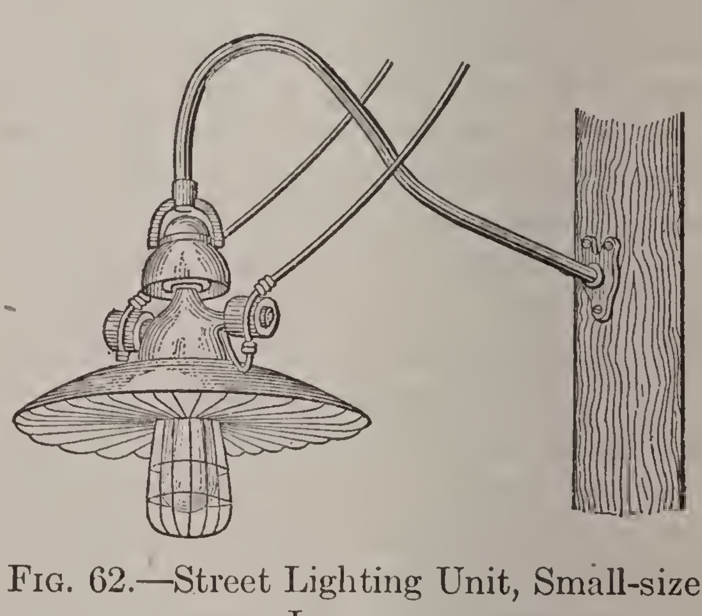


FIG. 62.—Street Lighting Unit, Small-size Lamps.

* A description of arc and incandescent lamps used for series circuits is given in Chapters 2 and 3.

† See paragraph 31.

in spite of the fact that both flame- and metallic electrode arcs are more efficient. The style of fixture used with incandescent lamps depends upon the service. For small towns and the thinly settled districts of larger places, bare lamps with enamel-steel reflectors are satisfactory (Fig. 62). For larger lamps, which are used in residential or business sections where appearance is important, the form of fixture shown in Fig. 63 is used. When used on series systems, a transformer is generally mounted inside the casing to allow the use of 15- or 20-ampere lamps on standard series circuits. For business streets and boulevards, ornamental standards are frequently used (Fig. 64). The single-light standards are equipped with a large tungsten lamp or a magnetite or flame-arc lamp. Multiple-light standards use gas-filled lamps. For series circuits, some form of **lamp cutout** must be provided to keep the circuit closed under all conditions. For arc lamps this is combined with the lamp mechanism and for incandescent lamps it is contained in the lamp socket and hood. With the adjuster-socket system, a reactance coil is shunted across each of the lamps (Fig. 61). This is so designed that when the lamp is operating very little current flows through the coil. When the lamp burns out, the entire current flows through the coil. The voltage drop of the coil is such that the amount of current is not affected greatly until about 20 per cent of the lamps are out. When the regulator system is used for incandescent lighting, a **film cutout** is employed. A porcelain receptacle containing two spring clips is mounted in the lamp hood. These

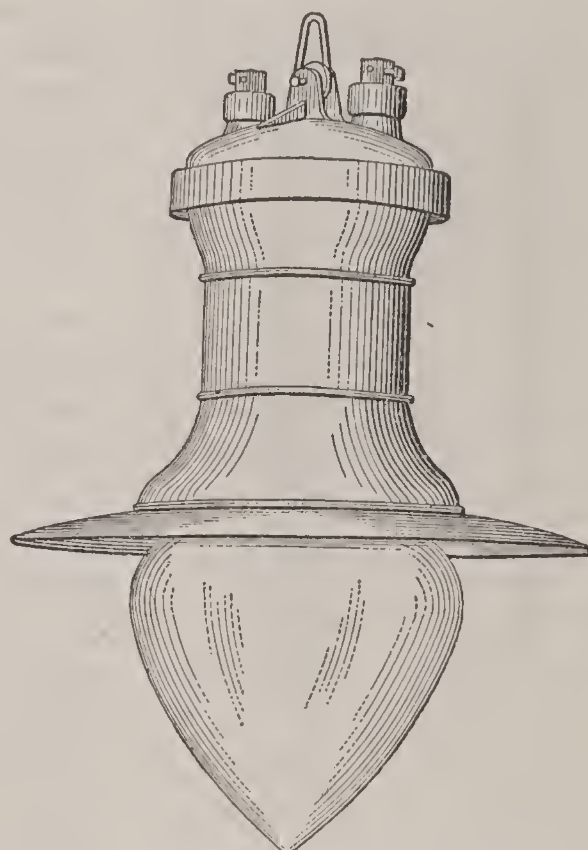
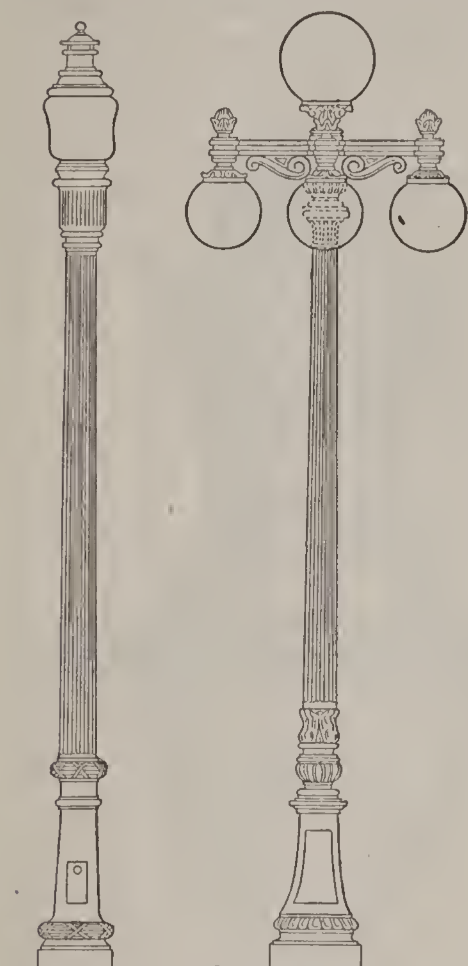


FIG. 63.—Typical Outdoor Unit for Gas-filled Tungsten Lamp.

clips are connected to the circuit and are in contact when the lamp is removed. The lamp is provided with a porcelain socket having corresponding spring clips which are separated by a thin insulating film. When the socket is plugged into the receptacle, the spring clips on the latter are separated and the current flows through the lamp. If the lamp burns out, the voltage at the lamp terminals rises and punctures the film, thus short-circuiting the lamp. The film punctures at about 400 volts.



a *b*

FIG. 64.—Ornamental Lighting Standards.

a. Single light unit for metallic-electrode or flame-arc lamps or large tungsten lamps. *b*. Multiple light unit for tungsten lamps.

135. The intensity of illumination required depends upon the use which is made of the light. In any case the required intensity is much less than is necessary for interior illumination. For thinly-settled districts, the illumination is usually sufficient only to define the road. Residence districts require a somewhat higher intensity to enable obstructions and irregularities in the pavement to be seen, and to assist in policing the streets. Business districts require a still higher intensity because the traffic is heavier and also for the advertising effect. Table 19 is representative of good practice.

136. Arrangement of Units. In general, no attempt is made to obtain uniformity of illumination, although when the units are closely spaced for "white way" lighting this condition is approximately fulfilled. In residence streets, where there are a number of lamps closely spaced, better results as regards visibility are secured if the lamps are all placed on one side of the street. As regards **size of unit**, it may be said that an installation of large lamps, widely spaced, costs less and directs the light onto the street at a better angle than a large number of small units. Sometimes small units must be used

because of the presence of trees. The **spacing** varies with the character of the street. For thinly settled districts, the spacing is great and frequently irregular. In such cases lamps are placed at street intersections and at the outer edge of curves in the road. The actual distance between lamps may vary from 500 to 1000 ft. For residence streets where small size units are used, 100-ft. spacing is satisfactory. If large units are used, they would be placed at each street intersection. For business districts the spacing varies from 100 to 200 ft., depending upon the size of unit and the importance of the street. **The mounting height** depends upon the size of unit and the presence of trees, etc. An increased height increases the cost of the installation and reduces the amount of light which reaches the street surface. The height should be from 15 to 18 ft. for small units and from 20 to 25 ft. for larger sizes.

Yard Lighting

137. Railway Yards. The lighting of the freight classification yards of a railroad must be sufficient to allow work to be carried on safely and accurately at night. The units employed for this purpose include flame-arcs, quartz lamps, gas-filled tungsten lamps and arc search-lights. The tracks in the yard are placed so closely together that as a rule it is impossible to locate poles between the tracks. The light units are therefore placed at the sides of the yard. Flame-arcs and quartz lamps should be mounted high enough to be out of the range of vision of the car riders. This requires that they shall be from 40 to 75 ft. above the ground. Gas-filled tungsten lamps with enameled steel reflectors can also be mounted in a similar manner. Another arrangement uses tungsten lamps with angle reflectors pointed away from the entrance to the yard. By this means, glare is eliminated and the lamps can be mounted lower, for example 30 to 40 ft. The units are spaced from 300 to 600 ft. apart. The **intensity** should average from 0.27 to 0.43 foot-candle and should not be less than 0.02 foot-candle.* Storage and loading yards do not need as high an intensity as this.

138. Factory Yards. Flame-arcs, quartz lamps or large gas-filled tungsten lamps are suitable for factory yards.

* National Electric Light Association. Report of Yard Lighting Committee, 1916.

Tungsten lamps are most commonly employed in new installations. The unit shown in Fig. 63 is very satisfactory. Unless there are high obstructions in the yard, a **mounting height** of from 20 to 30 ft. should be used. The **spacing** is generally irregular, because it depends so much upon the arrangement of the buildings. The lamps would be mounted at intersections of important roadways, with additional lamps between, if the distances are too great. For flame-arcs or quartz lamps, a spacing of from 300 to 600 ft. is satisfactory. Using 300- or 400-watt tungsten lamps, a spacing of about 300 ft. would be required. In some cases, a 200-watt lamp, with a closer spacing, can be used to advantage.

139. Tennis courts have been very successfully lighted by large tungsten lamps equipped with enameled-steel reflectors. With the **side-lighting system** six units are used on each side of the court. These consist of 400-watt gas-filled lamps equipped with 45° angle reflectors. The units are generally hung from cables run parallel to the side lines and about 2 ft. outside the court. The units are hung about 18 ft. high and spaced 15.5 ft. apart. With the **overhead-lighting system** four 1000-watt units and bowl-shape, enameled-steel reflectors with extension skirts are used for a single court. The extension skirts shield the lamps and prevent glare. The units are hung from a cable in a single row, the long way of the court and over the centre line. They are hung about 30 ft. high and are spaced about 28 ft. apart. Where there are **several courts** side by side, four 750-watt units are hung in a row between the courts. The mounting height and spacing are the same as when mounted over the centre line of the court. The side lighting system costs about 50 per cent more than the overhead system, but the former seems to be preferred by players.

Electric Signs

140. Illuminated Signs. Tungsten lamps are used generally for electric signs. Three different voltages are used: 12* volts of 2.5 and 5-watt capacity; 60* volts of 5-watt capacity; and 120* volts of 7.5- and 10-watt capacity. Where the signs are placed close to the streets, frosted lamps are used. Tungsten lamps are better than carbon lamps because they give a

* Lamps with slightly lower or higher voltages can be obtained.

more brilliant appearance to the sign and they also take less power. For flashing signs, they have the further advantage that they reach full candlepower very quickly (about one-tenth of a second) and so can be used for very rapid flashing effects which would be impossible with carbon lamps. When **direct current** is used, there are several different methods of wiring the lamps (Fig. 65). The multiple arrangement (*a*) is the simplest but can be used only for 120-volt lamps. When 60-volt lamps are used either (*b*) or (*c*) can be used. For 12-volt lamps, an arrangement similar to (*b*) or (*c*) would be used. For (*b*) there would be 10 lamps in series in each group and in (*c*) the total number of lamps in the sign would be divided into

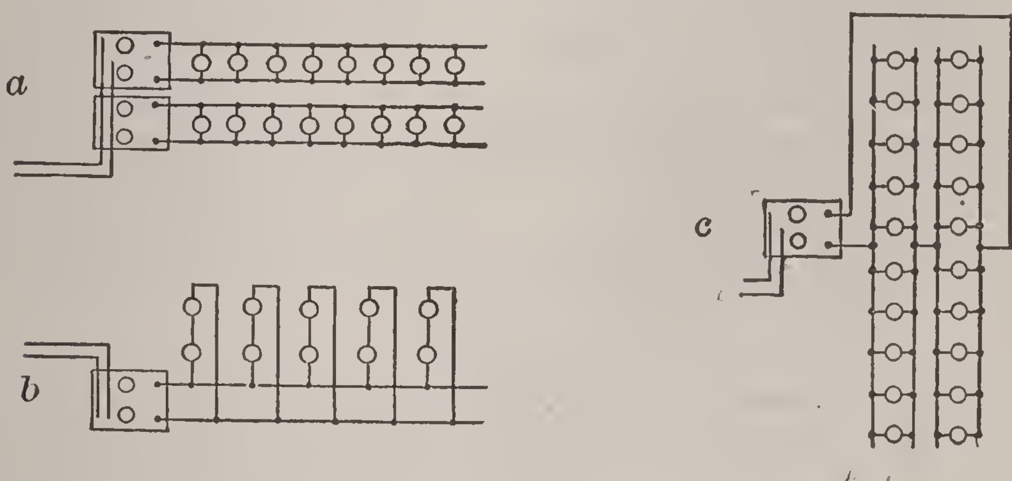


FIG. 65.—Connections for D.C. Signs.

10 groups and the lamps in each group placed in multiple. Arrangement (*c*) is better than (*b*) because if one lamp burns out none of the others are extinguished, whereas for (*b*) all the lamps in the same series are affected. It is very important to have the same number of lamps in each multiple group for arrangement (*c*), otherwise the voltages across the different groups would not be the same and some lamps would burn brighter than others. It is also important that all the lamps shall have the same rated voltage and watts for the same reason. If a lamp burns out, the voltage increases across the lamps in multiple with the burned-out lamp and decreases across the others. The amount of change depends upon the number of lamps in one multiple, a small number of lamps giving a large change in voltage. The amount of voltage increase on the remainder of lamps in a multiple having one or more burned-out lamps

is given in the following tabulation. This is for an arrangement of 10 multiples in series (12-volt lamps).

	Per Cent Voltage Increase.	
	20 Lamps in Each Multiple.	10 Lamps in Each Multiple.
1 lamp burned out..........	9	18
2 lamps burned out.........	18	40
3 lamps burned out.........	28	70
4 lamps burned out.........	40	

In general, it may be said that with 10 or more lamps in each group 1 lamp can burn out without causing the others to burn

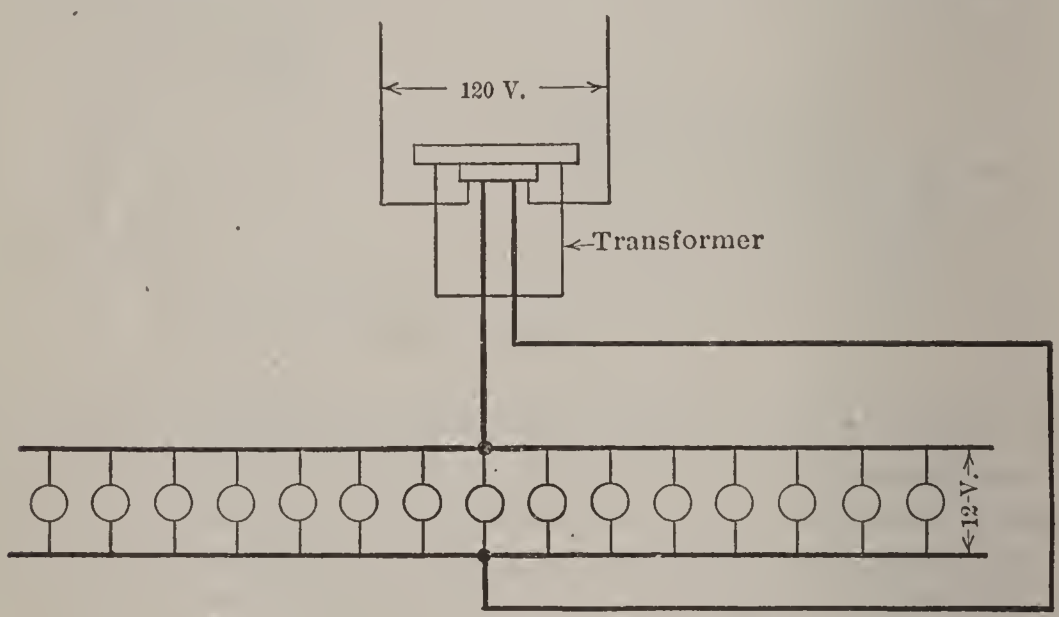


Fig. 66.—Connections for A.C. Signs.

out within a reasonable time. When 60-volt lamps are used with connection (*c*) there is a possible danger due to the short circuiting of one lamp. This would throw double voltage on the other group and would cause the lamps to burn out in a very short time, probably in less than a half hour. By close fusing, the lamps can be protected. It is necessary to select fuses which will carry the normal load but will melt when the current is about 50 per cent above normal. For this reason, the fuses

should be operated normally somewhat above their rating. When signs are used on **alternating current**, the lamps should always be arranged on the multiple system, using transformers when low-voltage lamps are required (Fig. 66). Special sign-lighting transformers having capacities from 50 to 2000 watts are made for this purpose. They are designed to give 12 volts on the secondary with 120 volts on the primary. The transformer should be mounted as close as possible to the lamps to reduce the length of the low-voltage circuit, since it is necessary to keep the drop down to a very low value. For this reason, on large signs, it is best to use several small transformers rather

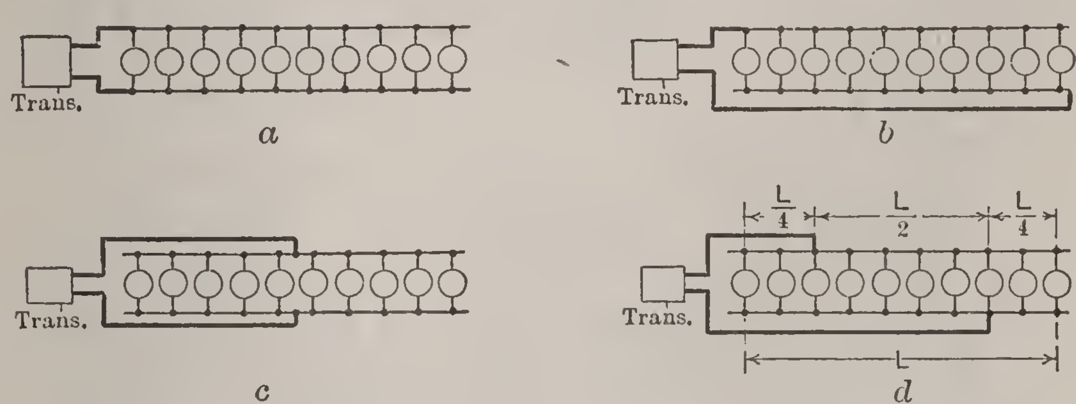


FIG. 67.—Connections for Low-voltage, Multiple Sign Lamps.
Taking the maximum voltage difference between lamps as 1 for (*a*), the other connections give differenees as follows: (*b*) 0.25; (*c*) 0.25; (*d*) 0.06.

than one large unit. The method of feeding low-voltage multiples is important (see Fig. 67). System (*a*) gives the greatest difference in voltage between lamps. This is not important for 110-volt wiring, but for low-voltage systems (12 volts) the increased current may cause a large voltage difference. System (*d*) is best for low-voltage work. The maximum voltage difference should not exceed about 4 per cent of the lamp voltage. For such low-voltage systems, the feeders between the transformers and the lamps must be large enough to keep the drop down to about 2 per cent of the lamp voltage; in other words, the drop should be about 0.25 volt.

141. Sign Flashers. Flashing signs are more satisfactory than fixed signs because they attract more attention. **Thermo-flashers** (Fig. 68*a*) have an interrupter which is operated by the heating effect of the lamp current. In the type shown, the lower arm is wound with a resistance wire which is connected

to the two terminals. When the arm is cold, the contact is open and all the current for the lamps flows through the resistance. This reduces the current to the point where the lamps barely glow. The resistance heats the arm upon which it is wound, causing it to expand and the contact to close. This short-circuits the resistance and the lamp lights. As soon as the arm cools down the contact is opened and the lamp goes out. This process is repeated at frequent intervals. Flashers

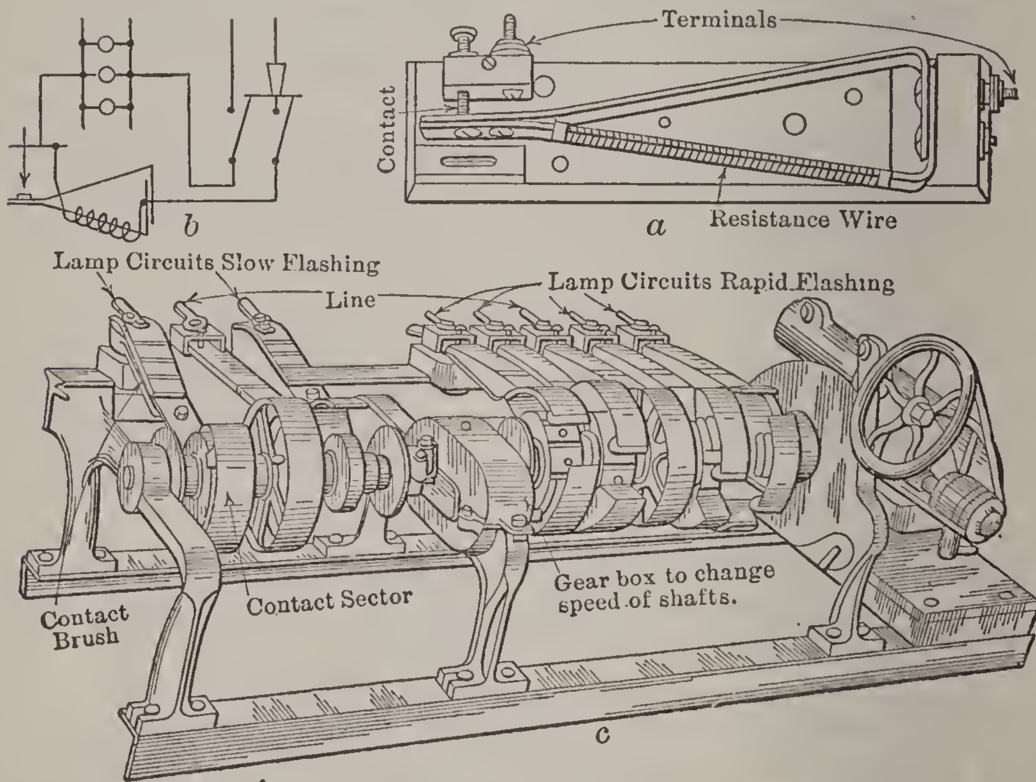


FIG. 68.—Sign Flashers.

a. Thermo-flasher; 165 watts, 110 volts. *b*. Diagram of thermo-flasher. *c*. Motor flasher having four lamp circuits (3 amperes each), for high-speed flashing effects such as revolving borders and two circuits (10 amperes each), for slow effects, throwing the circuits on alternately. (Betts & Betts.)

of this type are made in various capacities up to 330 watts to suit different numbers of lamps. They will work well only at approximately rated load. The larger sizes have **spark eliminators** consisting of condensers shunted across the contacts. A somewhat similar type with the contacts in a vacuum is made in capacities up to 12 amperes single pole and 25 amperes double pole. Thermo-flashers are made for operation on direct and alternating current. The disadvantage is that the rapidity of the flashes cannot be controlled accurately and therefore

they can be used only for simple flashing effects. **Magnetic flashers** employ a switch operated by an electro-magnet. The time "on" and "off" is controlled by a dash pot. These are used for the same class of service as the thermo-flashers but are not as satisfactory. **Motor-operated flashers** (Fig. 68*c*) are used for large signs and complicated effects where the

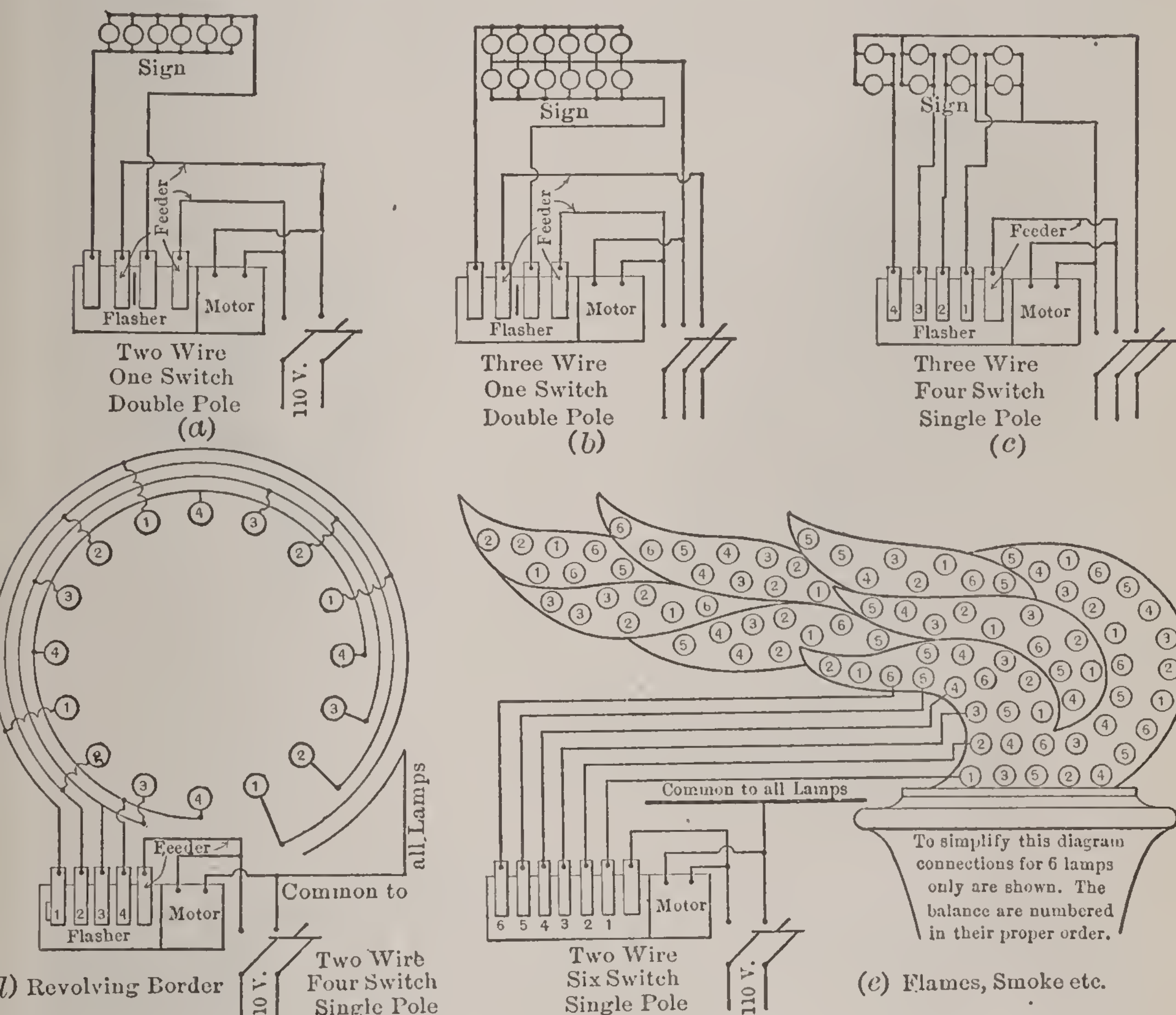
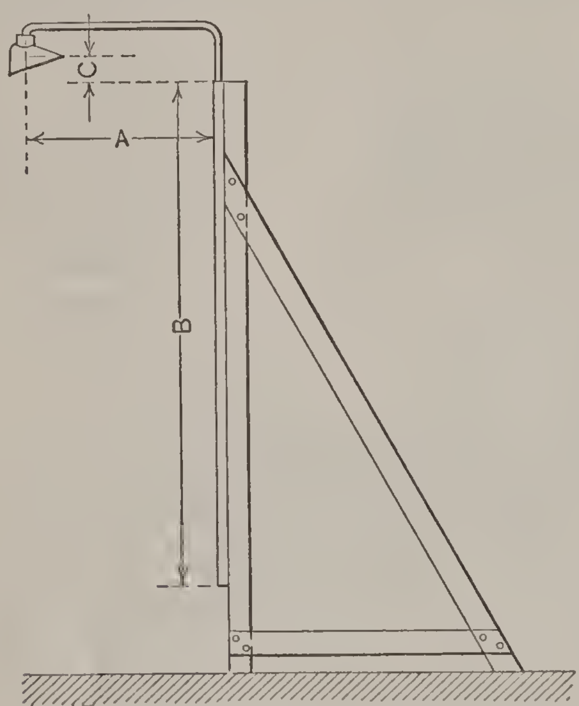


FIG. 69.—Diagrams for Motor-flashers.

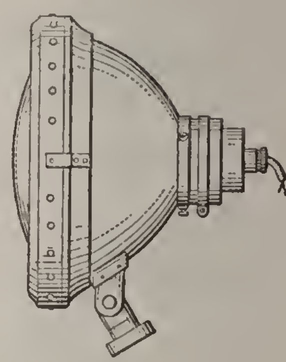
(*a*), (*b*) and (*c*) are for slow-speed "on and off" flashers; (*d*) and (*e*) use high-speed flashers. (Betts & Betts.)

different lamps must be turned on in a definite order. The various lamp circuits are closed by brushes which strike contact sectors mounted on a motor-driven shaft. Generally several of these sectors (controlling different groups of lamps) are mounted together and supplied with current through a contact wheel and brush. The sectors are provided with sections which can be changed in different ways to adjust each circuit indepen-

dently. For 110-volt circuits the Code allows a maximum of 30 amperes for a single-pole switch. In the type of flasher shown, it is customary to use double-pole switches above 20 amperes. For 220 volts, the capacity is about 50 per cent less. For low-voltage work much larger currents can be carried. When a.c. signs are used with transformers and low-voltage lamps, the flasher is connected in the secondary circuit, except for very large signs, where a separate trans-



a



b

FIG. 70.—Flood Lighting.

a. Lighting bill board with angle reflectors. *b*. Flood lighting projector. Used to illuminate large signs and building exteriors, from a distance. In (*a*) the distance *A* should be about 0.5 *B*, except when *B* is less than 9 ft., when *A* should be about 0.75 *B*. Distance *C* should be about 1 ft. Spacing between lamps should be about 6 ft. for signs up to 10 ft. high (*B*); above this, spacing should be 0.5 *B*.

former could be used for each group of lamps. Diagrams for flashing signs are given in Fig. 69. In diagram (*a*), all the lamps are thrown on and off together, but a double-pole switch is used because of the large load. When single-pole flashers are connected as in (*c*), the two sides should be balanced as nearly as possible.

142. Flood lighting for bill boards and painted signs is now commonly used. Tungsten lamps mounted in angle-type enameled steel reflectors are installed in front of and slightly

above the top edge of the bill board. The size of lamp varies with the size of the sign. For a brilliant illumination of 10 to 12 foot-candles about 2.5 watts per square foot of surface should be allowed. For moderate illumination of 5 to 7 foot-candles about 1.75 watts per square foot are needed. The arrangement is shown in Fig. 70. For the ordinary sign from 9 to 12 ft. high, 200 or 100-watt, gas-filled tungsten lamps are commonly used. For large signs, which cannot be conveniently lighted as shown in Fig. 70*a*, **flood-lighting projectors** are used. A special form of tungsten lamp with a concentrating mirror reflector is employed so as to produce a strong beam of light. The projector can be located on a pole or the roof of a building at a considerable distance from the sign. Projectors are also used for lighting excavations for night work, for trap shooting, etc.

PART II.—ELECTRIC POWER SYSTEMS

CHAPTER 9

MOTORS FOR INDUSTRIAL PURPOSES

143. Advantages of the Electric Drive. In modern shop installations, the drive is almost invariably electrical. The old mechanical drive, where the engine is connected to the machines by long lines of shafting, with numerous jackshafts and belts, is seldom adopted now for a new installation, particularly for large plants. Some of the advantages of the electric drive are: * (*a*) An **increase in production.** (*b*) **A greater flexibility** of arrangement of machines. (*c*) **A clear headroom** is provided. This permits the free use of overhead cranes, and results in better illumination and greater freedom from accidents. (*d*) Because the power can be transmitted electrically for considerable distances with small loss, **the power plant can be centralized** where the power can be generated most efficiently. Tests of shafting drives indicate that the loss varies from 25 to 75 per cent and in most cases is about 50 per cent of the power generated.† Furthermore, the loss is nearly constant regardless of the load. With the electric drive the loss depends upon the amount of power transmitted, and the total loss, including that in generators, feeders and motors, is only from 20 to 30 per cent. (*e*) **The electric service is more reliable,** since a breakdown usually puts out of commission only a small part of the motors. (*f*) **It is possible to operate sections of the factory** at high efficiency when the other sections are shut down, whereas, without the electric drive, possibly all the shafting in a large mill might have to be operated for the purpose of driving one

* See paragraph 187.

† A. F. Strouse, *Electric Journal*, 1912, p. 209.

or two machines. (*g*) **Speed control is easily secured** by means of the electric motor. Instead of speed changes in large steps by changing gears or shifting belts, a very large number of small speed changes can be easily obtained. This results in keeping the operating speed closer to its economical limit and thus increases the production. (*h*) **A study of machine performance** can easily be made by introducing meters in the motor circuit. By this means, an accurate record may be obtained of the power requirements for a particular operation and any excessive demand for power due to the faulty working of the machine is easily detected.

144. Systems of Power Supply. Of the two systems of power supply,* the multiple or constant-potential system is the only one used in this country for the operation of motors. At one time the series system was used for this purpose, but the advantages of the multiple system, due to the lower voltages on the motors and the entire independence of each machine, makes it the only practical system for general power service. No description will therefore be given of motors or their accessories for use on series systems.

145. Classes and Types of Motors. Motors for industrial purposes are divided into two classes, direct current and alternating current according to the power supply used. The **d.c. motors** comprise three general types: series, shunt, and compound motors, depending upon the type of field winding used. The **a.c. motors** are also divided into three general types: induction, synchronous and commutator motors. The a.c. motors are further subdivided into single-phase and polyphase motors, the latter including both two-phase and three-phase motors. Electric motors are also classified according to their performance. With **constant-speed motors**, the speed is practically constant regardless of the load (for example shunt motors) the maximum variation between no load and full load not exceeding about 20 per cent. In the case of **varying speed motors** such as series motors, the speed decreases greatly with increase in load. **Adjustable-speed motors** are so constructed that the speed can be adjusted gradually over a wide range, but when once adjusted the speed remains practically constant regardless of the load. Examples of this type are the specially designed shunt or compound motors.

* See Chapter 12 for description.

DIRECT-CURRENT MOTORS

146. Series Motors. In this type of motor the armature and field windings are connected in series, so that the entire armature current passes through the field circuit. The field is therefore wound with a small number of turns of large wire,

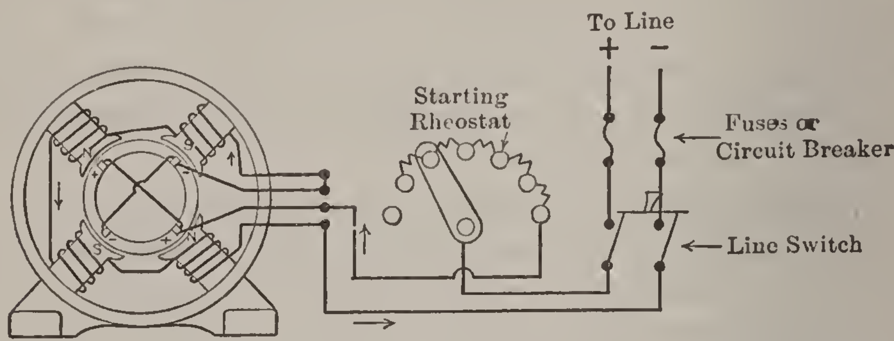


FIG. 71.—Diagram of Connections for a Series Motor.

which will safely carry the armature current and will give a small drop in the field winding (Fig. 71). Since the current in field and armature is the same, the strength of the field increases as the armature current is increased due to an increased load. Hence series motors can start heavy loads without draw-

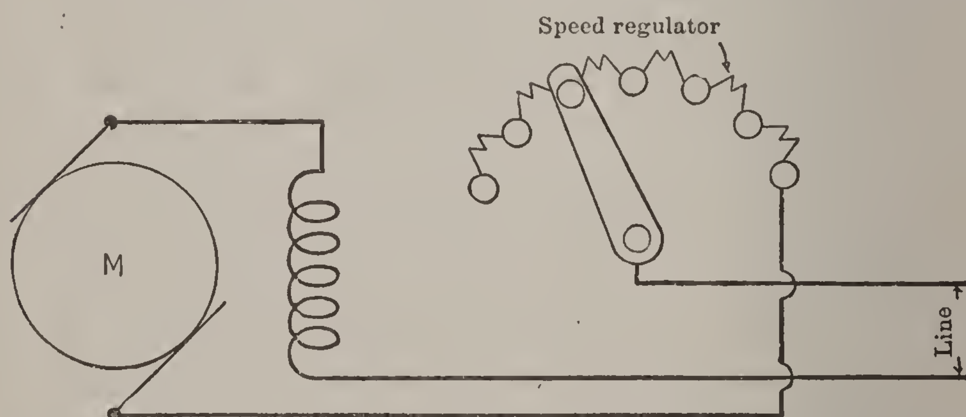


FIG. 72.—Connections for Speed Adjustment of a Series Motor.

ing an excessive amount of current from the line. The series motor is of the varying-speed type, since the speed rapidly increases as the load is decreased. If the load is entirely thrown off, a dangerously high speed may result, and therefore series motors should never be belted to the load, but should be either direct connected or equipped with a gear or chain drive.

Speed adjustment may be accomplished by means of a resistance in series with the motor (Fig. 72). This reduces the voltage on the motor and thereby reduces the speed. There is considerable loss in the rheostat, but since a series motor requiring speed adjustment is used only intermittently, this does not result in a large loss in power. This rheostat would be combined with the starting rheostat.* The direction of rotation may be changed by reversing either the connections of the field or armature, but not both. Because of the ability to start heavy loads quickly, series motors are used principally for electric cars, cranes and hoists, which do not require a constant speed.†

147. Shunt Motors. The shunt motor has its armature and field windings connected in parallel to the line. The field

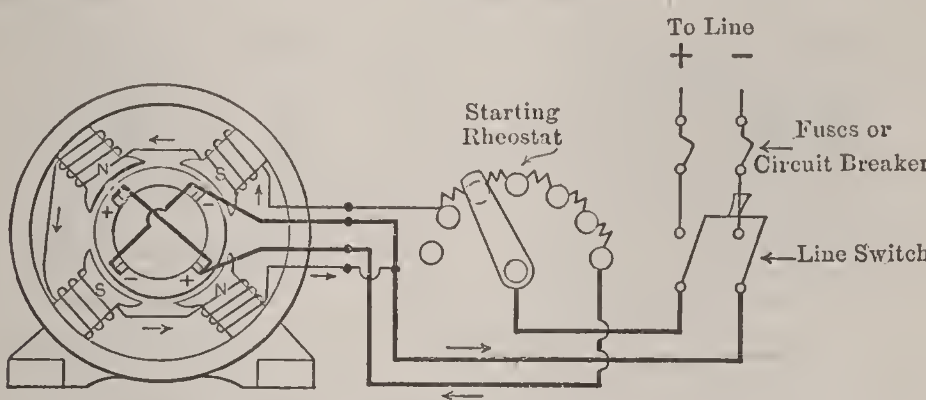


FIG. 73.—Diagram of Connections for a Shunt Motor.

winding therefore consists of a large number of turns of fine wire which gives a high resistance to the field circuit (Fig. 73). This limits the current taken by the field to from 1 to 5 per cent of the full-load current of the motor. Because the field is connected directly to the line, the field strength remains constant‡ regardless of the amount of current in the armature. The motor will not start as heavy a load as the series motor without exceeding a safe current, but the starting effort is sufficient for most industrial conditions. Since the field of the shunt motor is kept at a constant strength regardless of the load, the motor maintains practically constant speed for all

* See paragraph 175, Chapter 10.

† See tabulation in paragraph 150.

‡ Neglecting the effect of the armature current, which weakens the field strength slightly.

loads. With the motors usually employed, the speed drops not more than 5 per cent from no load to full load. When interpole motors are used, the drop in speed is from 3 to 4 per cent. **Speed adjustment** may be secured by means of a rheostat in the field circuit (Fig. 74*a*). Cutting in resistance and thereby weakening the field increases the speed. If the field is weakened too much, there is trouble from sparking at the commutator, the ordinary shunt motor allowing an increase of only 15 to 30 per cent above normal speed. By the use of interpoles,* a larger speed adjustment may be obtained. For most purposes, a motor with a high speed four times the lowest speed (4 to 1 ratio) is sufficient. Higher ratios may be obtained if necessary. Speed adjustment may also be secured by the use of a rheo-

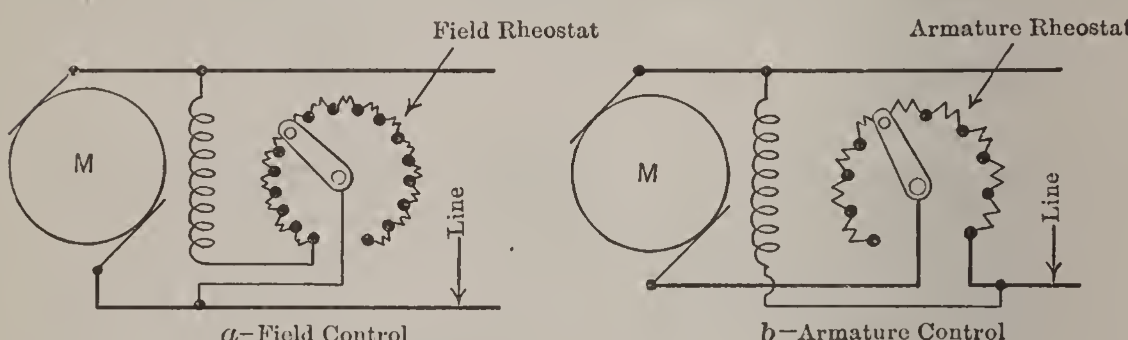


FIG. 74.—Connections of a Shunt Motor for Speed Adjustment.
Starting rheostat, line switch and fuses not shown.

stat in the armature circuit (Fig. 74*b*). Inserting resistance in this way reduces the speed, but causes a large loss of power in the rheostat. If the speed is reduced 50 per cent, nearly half the power taken from the line is lost in the rheostat. If the speed is reduced to 50 per cent of normal when carrying full-load current, it will be about 75 per cent of normal when carrying half-load current. If all the load is thrown off, the speed would increase still more and become practically the same as if the rheostat was not in circuit. With changing load, therefore, the armature rheostat would require continual adjustment in order to maintain a constant speed. In brief, the motor with armature rheostat acts somewhat like a series motor, and it is therefore not suitable for many applications, such as driving lathes and other machine tools which require a constant speed. By the use of the field rheostat (Fig. 74*a*), however,

* See paragraph 149.

the motor speed, having once been adjusted to the proper value, will remain constant (with perhaps 5 per cent change) regardless of the load on the motor. The loss in the field rheostat is also much less than for the arrangement shown in Fig. 74*b*. For these reasons, the speed of a shunt motor is usually adjusted by means of a field rheostat (Fig. 74*a*). The use of the armature rheostat (Fig. 74*b*) is confined to motors driving ventilating fans, blowers and centrifugal pumps, where a speed reduction is required, and the load decreases with a decrease in speed. When either an armature or a field rheostat is used for controlling the speed, it is usually combined with the starting rheostat,* although separate rheostats may be used

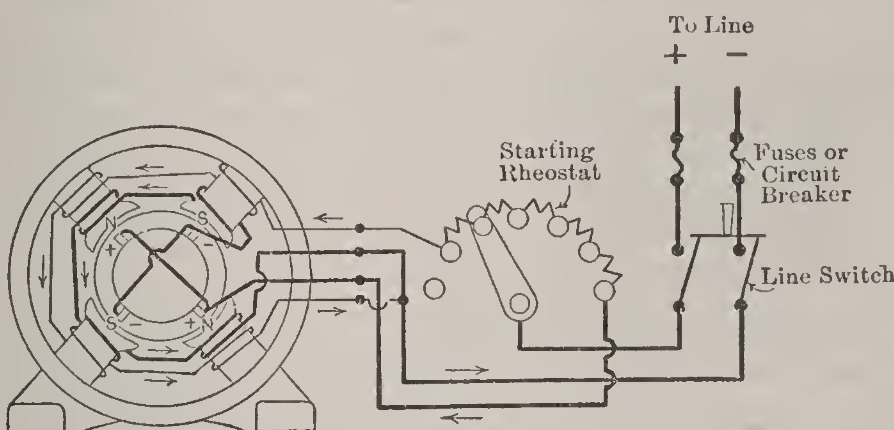


FIG. 75.—Diagram of Connections for a Compound Motor. (Cumulative Compound.)

for starting and for changing the speed. Adjustment of speed can also be made by shifting the armature partially out from between the poles, or by changing the position of the field poles. These methods have only a limited use. The direction of rotation of a shunt motor may be reversed by changing the connections to either the armature or the field. Since shunt motors are constant-speed machines, they are used principally for driving machine tools, wood-working machinery, pumps, etc.†

148. Compound Motors. This motor is a combination of a series and shunt motor. It has two field windings, a shunt winding connected across the line and a series winding connected in series with the armature. The two fields are so connected as to give the same polarities, and hence the field strength increases as the load increases (Fig. 75). When connected

* See Fig. 92. † See tabulation in paragraph 150.

in this manner, the machine is called cumulative compound or sometimes simply compound. The operation of this motor depends upon the relative strength of the two fields. If the series field is weak, the machine acts more like a shunt motor (constant-speed type), and if the series field is strong it acts like a series motor (varying-speed type). The compound motor will start heavier loads than the shunt motor, but it is not quite as good in this respect as the series motor. On the other hand, there is no danger of the compound motor reaching a dangerously high speed if the load is entirely thrown off. The drop in speed as the load increases is greater than for the shunt motor (15 to 25 per cent change from no load to full load), but it is not as great as the series motor. **Speed adjustment**, when required, is accomplished by means of a rheostat in the shunt-field circuit (Fig. 76). The direction of rotation may best be changed by reversing the polarity of the armature terminals. If the reversal of rotation is made by changing the shunt terminals, the series terminals must also be reversed so that the two field windings will continue to act together and not oppose each other. Compound motors, with relatively weak series fields (about 10 to 15 per cent series winding) will start fairly heavy loads. They are used for planers and large printing presses. Motors with a stronger series field (usually about 20 to 50 per cent series winding) give a larger drop in speed. They are used for punch presses, shears, bending rolls, etc., which have heavy momentary loads. To equalize the load on the motor, heavy flywheels are used. When the load is applied, the motor slows down and the flywheel helps carry the load. After the heavy load is removed, the motor speeds up the machine ready for the next stroke. If the series winding of a compound-wound machine is reversed, so that it opposes the shunt winding, the field strength is decreased as the load is increased, and we have a **differential motor.** The effect of this is to maintain a constant speed, with changing load, the difference in speed between no load and full load being

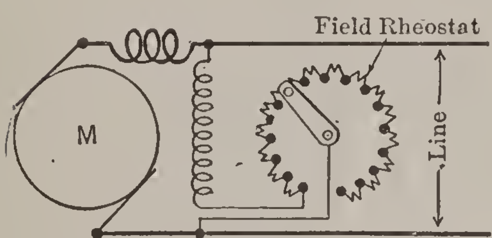


Fig. 76.—Connections of Compound Motor for Speed Adjustment.
Starting rheostat, line switch and fuses not shown.

less than for an ordinary shunt motor. It is possible, however, to design shunt motors with interpoles* so that the speed will be practically constant. There is therefore very little need for differential motors, and they have the disadvantage that the speed is likely to be unstable at heavy loads. They are therefore not used in practice. **The series-shunt motor** is a compound machine with a very heavy series and a light shunt winding. The speed characteristic is nearly like a series motor, the shunt winding, however, limiting the no-load speed to from 60 to 100 per cent higher value than the full-load speed. The motor is used where a varying speed characteristic is desired and where there would be a possibility of overspeeding if an ordinary series motor was used. Series-shunt motors are used for auxiliary service in steel mills and for crane motors.

149. Interpole Motors. D.C. motors are frequently built with small poles (interpoles or commutating poles) placed be-

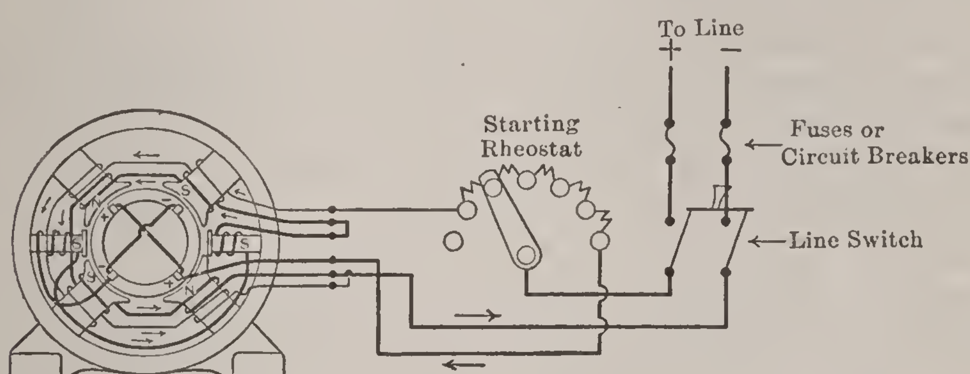


FIG. **77**.—Diagram of Connections for an Interpole Motor. (Compound Wound.)

The same connections would apply to a shunt interpole motor with compensating winding. See par. 149.

tween the main poles. Interpoles are used with series, shunt and compound machines. Fig. 77 shows the connections for a compound interpole motor. The connections for a series interpole motor would be the same with the shunt field omitted. For a shunt interpole machine, the series winding on the main field poles would be omitted except where a compensating winding is used. This is described later in this paragraph. Fig. 77 shows a four-pole motor, with only two interpoles. This arrangement is used for motors up to about 50 hp. capacity.

* See paragraph 149.

For larger sizes, there would be as many interpoles as there were main poles. These interpoles reduce the tendency to sparking on overloads, and in the case of shunt-wound motors they keep the speed more nearly constant at all loads. Interpoles are used particularly for shunt motors which must have a wide speed adjustment, and for motors which must be frequently reversed, so that satisfactory commutation may be secured without shifting the brushes when operating in either direction. Interpoles are also of service for motors which are subjected to heavy overloads, and where otherwise there might be trouble from sparking. The starting and running characteristics of series, shunt and compound motors, as described in paragraphs 146, 147 and 148, apply also to these motors when equipped with interpoles. The interpole winding generally used on shunt-wound machines is of such a strength as to produce a very small speed change with varying load and in some cases the speed at full load is higher than at no load. This is likely to cause unstable operation, with heavy surges of current and changes of speed. To correct this, **a compensating winding** is used. This is a light series winding, consisting of a few turns placed on the main field poles and connected in series with the armature (Fig. 77). This winding is so connected that its polarity is the same as the main shunt winding and hence it assists this winding and produces stable running conditions. In general, for industrial applications, interpole motors are commonly used. The direction of rotation of interpole motors may be reversed in the manner already described,* but in doing so *the interpole winding should always be considered as a part of the armature circuit and the polarity of armature and interpole winding should always be kept the same.* If the connections of the interpole winding to the armature are reversed, the machine will spark badly.

150. Applications of D.C. Motors. The applications of the various kinds of d.c. motors are determined by their performance when starting and running. The following tabulation gives this information, together with information regarding the principal kinds of machines for which they are best suited. This table may be used to select a motor for driving a particular machine, provided the starting and running requirements of the machine are known.

* See paragraphs 146, 147 or 148.

Performance of D.C. Motors[1]

Type.	Starting Torque.	Running Performance.	Applications.
Series	Very large for heavy currents. Small for currents less than half full load.	Speed varies widely with load. Motor will reach a dangerous speed if load is all thrown off.	Electric railways, cranes and small hoists, small air compressors, small elevators, propeller fans.
Shunt	Less than compound motor for large currents. More than compound for small values of current.	Speed practically constant. About 3 to 5% drop from no load to full load.	Wood-working machinery, screw machines, lathes, shapers, drills, blowers, centrifugal pumps, line shafts, pressure blowers, centrifugal fans, printing presses, conveyers.
Compound (cumulative)	Less than series for large currents. Less than shunt, but more than series for small currents.	Speed falls off rapidly with increase in load, the amount depending on strength of series winding.	Punch presses, large shears, drop hammers, planers, large printing presses, passenger elevators, bending rolls.
Compound (differential)	Very small unless series winding is cut out when starting.	Speed may be held more nearly constant than with shunt motor. Is likely to be unstable at heavy overloads.	Special constant-speed applications for small power.

[1] See also paragraph 188.

Alternating Current Motors

151. Polyphase Induction Motors. A polyphase-induction motor (either two-phase or three-phase) consists of a stationary part or **stator** containing windings to which the power supply is connected, and a rotating part or **rotor** which has no electrical connection with the supply, but in which current is produced by induction, hence the name. The motors are of two kinds, one having a squirrel-cage or short-circuited rotor and the other using a rotor winding connected to slip-rings. The latter type is sometimes called a phase-wound motor. The induction motor

is similar in its speed changes to the shunt motor, being essentially a constant-speed machine, although by special means the speed may be varied. The motor produces a lagging power factor,* but this is quite high at or near full load. At light loads, however, the power factor is very low.

152. Squirrel-cage Induction Motors. In this type of motor, the rotor winding consists of heavy bars short-circuited at the ends by rings. The absence of any commutator or slip-rings makes it the most rugged and reliable type of motor built. It is, however, a constant-speed device, being similar to the shunt motor in this respect. The speed change with load is about the same as the shunt motor, there being a drop of from

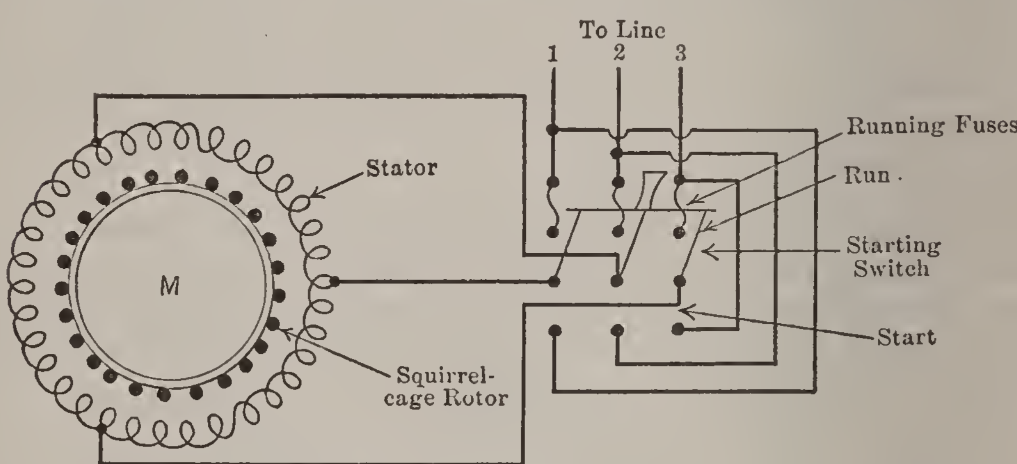


FIG. 78.—Diagram of Connections for a Squirrel-cage Induction Motor. Three-phase.

Connections are those used for small motors. For large motors an auto-starter is used. See Fig. 79.

3 to 6 per cent in speed from no load to full load. The speed cannot be as easily changed as in the shunt motor, and if an adjustable-speed motor is required the slip-ring type must be used. Squirrel-cage motors are used for driving line shafts and machinery where the speed does not need to be varied.† The arrangement of connections for a squirrel-cage motor is shown in Figs. 78 and 79. In some cases, where the speed changes with load are not important, but where the motor must start heavy loads, as in crane service, a squirrel-cage motor with a high resistance rotor is provided. This reduces the current required to start the load, but the speed variations with changes in load are greater and the efficiency is lower.

* See paragraph 168.

† See tabulation, paragraph 160.

The running performance of this motor is somewhat like the compound motor. The principal applications are small cranes, punch presses, etc.* The direction of rotation of a three-phase motor may be changed by reversing any two of the connections to the stator. A two-phase (four-wire) motor may be reversed by reversing the connections of either of the two phases. A

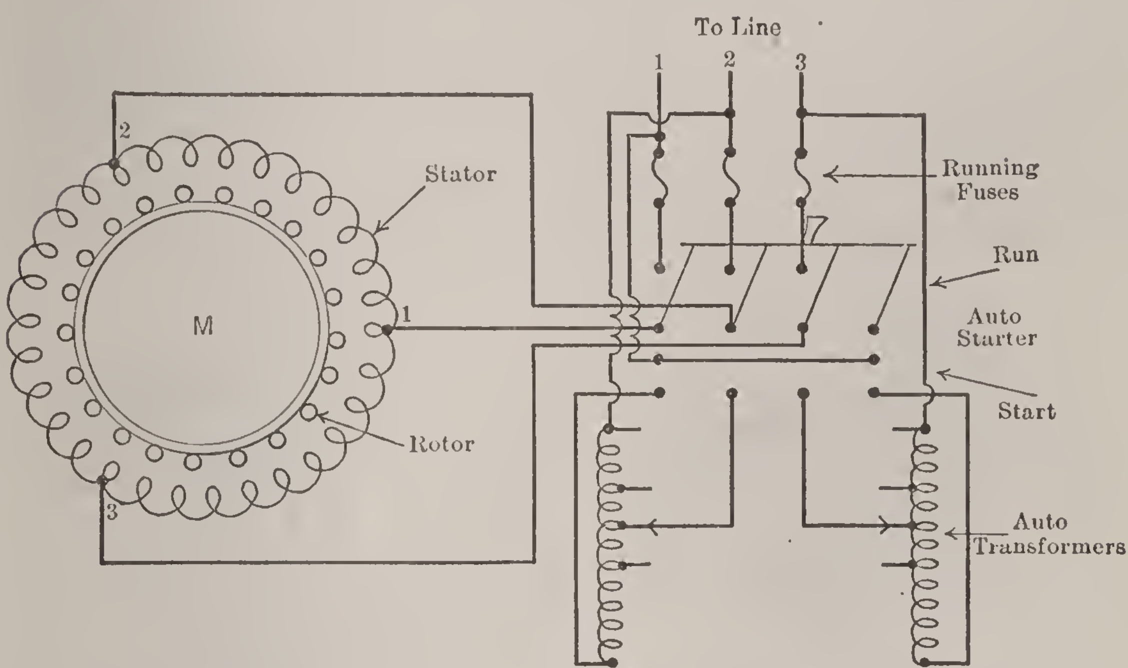


FIG. 79.—Diagram of Connections for a Squirrel-cage Induction Motor. Three-phase with Auto-starter.

Line switch not shown.

two-phase (three-wire) motor may be reversed by reversing the outside wires.

153. Slip-ring Induction Motors. This type of motor has a rotor winding consisting of insulated coils connected usually like the armature of a three-phase generator. The terminals are frequently connected to slip-rings so that external resistances may be connected into the rotor circuit (Fig. 80). In some cases the slip-rings are omitted and the resistances are mounted inside the rotor frame. By the use of these resistances, the amount of current taken from the line when starting a heavy load is very much less than that required for a squirrel-cage motor. The resistances are short-circuited after the machine has reached full speed. The motor then operates practically

* See tabulation, paragraph 160.

like a squirrel-cage motor and gives a nearly constant speed at all loads. If it is desired to change the speed of the motor, the resistances may be left in circuit after the motor has been started, and if they are properly designed to carry the current continuously, the speed may be adjusted to any desired value, lower than the normal speed, by changing the amount of resistance. When this is done, the motor operates like a shunt motor with resistance in the armature circuit. (Par. 147.) Consequently the speed will change greatly if the load changes and will rise to practically normal speed if all the load is thrown off. In addition, there is a large loss of power in the resistances, and hence the motor is very inefficient under these conditions. The slip-ring motor is used where heavy loads must be started,

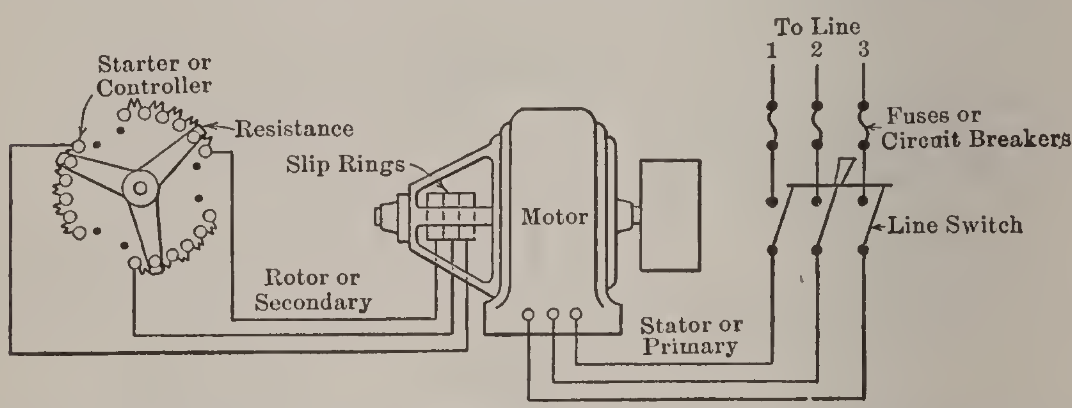


FIG. 80.—Diagram of Connections for a Slip-ring Induction Motor.

as, for example, air compressors, and also for very large motors, where it is necessary to limit the starting current to a minimum value. It is also used for varying-speed work such as cranes and elevators, and for adjustable-speed duty as required for ventilating fans.

154. Multi-speed Induction Motors. The speed of an induction motor may be changed by changing the number of poles for which the stator is wound. This is accomplished by special arrangement of the stator windings. By this method it is possible to obtain two and in some cases four different speeds. The speed with each connection is nearly constant, regardless of the load. The complication of the connections and the small number of speeds available make the applications of this type of motor rather limited.

155. Commutator-type Induction Motor. A special form of induction motor, called a **brush-shifting motor,** has been recently

introduced by the General Electric Company. The stator is of the usual type, but the rotor is practically like a d.c. armature with commutator and brushes. Power from the line is supplied to both stator and rotor (in the latter case, usually by means of transformers). The position of the brushes determines the speed, and the motor can be started, speed adjusted, or direction of rotation changed by properly shifting the brushes. These motors act somewhat like series motors when the speed changes. **Other types** of commutator induction motors have also been used to some extent in this country where adjustable

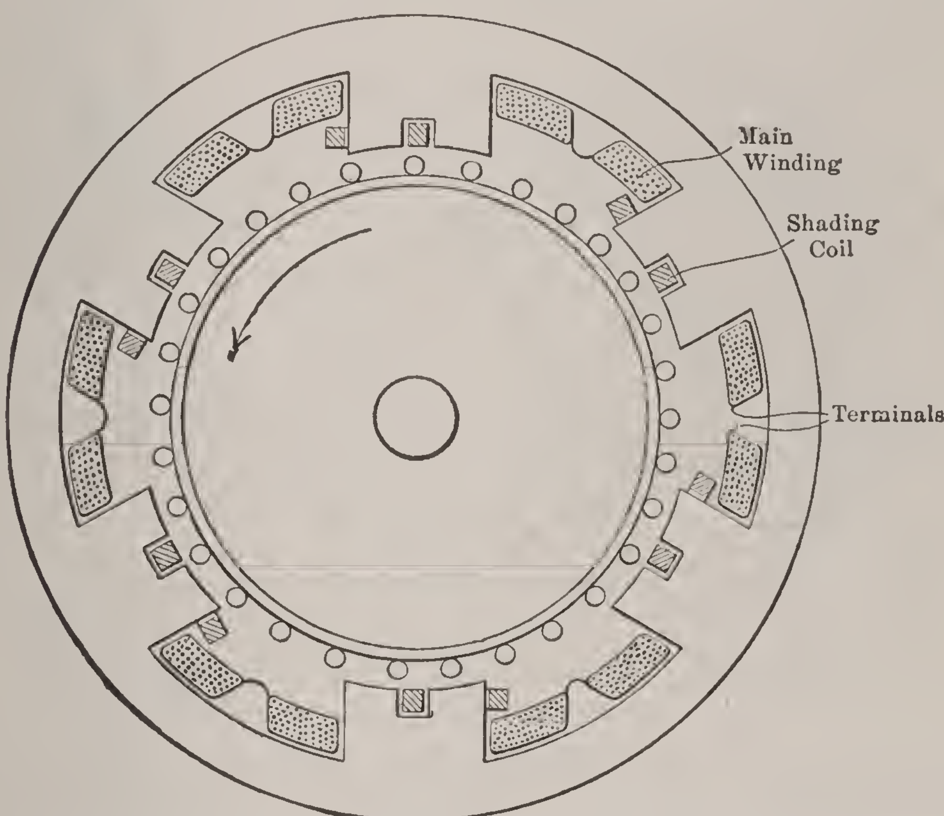


FIG. 81.—Single-phase Motor with Shaded Poles.

speed is required. Since they employ auxiliary machines, however, they are only adapted for large-size motors.

156. Single-phase Induction Motors. The foregoing discussion applies to polyphase induction motors, either two- or three-phase. There is a limited demand for single-phase induction motors in small sizes and this has been met in several ways. A motor with a single-phase winding on the stator and with a squirrel-cage rotor is not self-starting. If started by hand in either direction, it will continue to run in the particular direction chosen, and if the load is not too great will increase in speed

until the normal value is reached. For practical use, therefore, some means must be employed to start the motor. For very small motors, for driving fans and similar purposes, a **shaded pole** is used. This is shown in Fig. 81. This consists of a heavy copper ring surrounding a portion of each pole piece. The effect of this is to start the motor in the proper direction, after which it will quickly reach normal speed. If the motor is to run in the opposite direction, the copper ring must be put on the other side of each pole. A **split-phase** arrangement

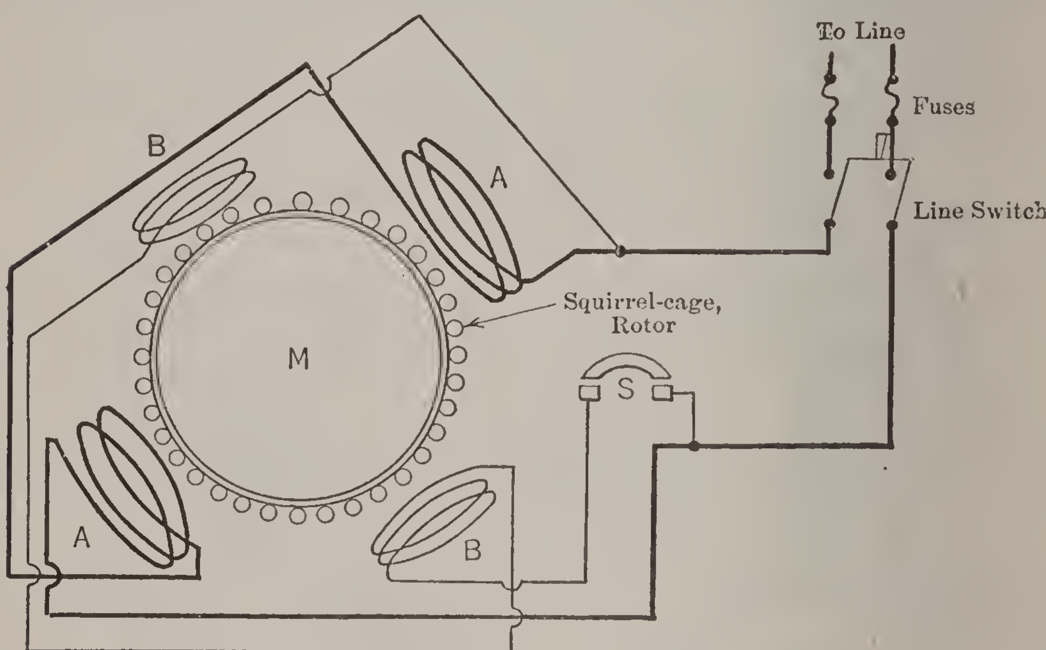


FIG. 82.—Diagram of Connections for a Split-phase, Single-phase Induction Motor.

AA. Main field winding. *BB*. Starting winding. *S*. Starting switch, which is closed when motor first starts. A centrifugal clutch mounted on the motor shaft opens *S* after motor has come up to speed.

is also used. In one type the motor has a main stator winding and an additional starting winding. By proper design of these two windings, there is produced a rotating field somewhat like that in a polyphase motor, and therefore the machine is self-starting (Fig. 82). A squirrel-cage rotor is used. The starting torque is not as good as for polyphase motors, so that for the larger sizes a friction clutch is used. With this arrangement the rotor alone is started, and after the machine has reached nearly full speed the clutch acts and throws on the load. Split-phase motors of this type are provided with a switch which is operated by centrifugal action and cuts out the starting winding

after the motor has started. Motors of this type are made in sizes up to 1 hp. The split-phase motor of another manufacturer uses a standard three-phase stator winding with a starting box which connects resistance and reactance in the circuit when starting. A friction clutch picks up the load after the machine has reached the proper speed. The split-phase motor is at a disadvantage as regards starting torque, and the friction clutch frequently gives trouble. This type of motor is therefore used in small sizes (up to 1 hp.), the repulsion motor* being used for larger sizes. Single-phase induction motors are more expensive than polyphase motors and are only used

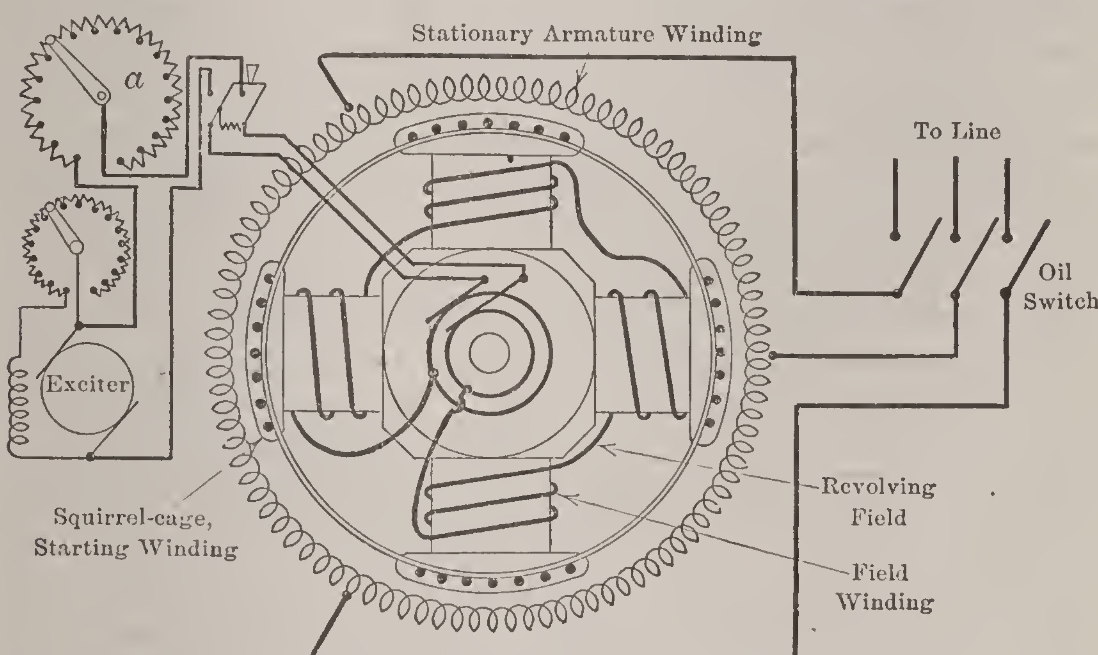


FIG. 83.—Diagram of Connections for a Self-starting Synchronous Motor.

Motor is started with field switch open. An auto-starter is used for starting at reduced voltage similarly to a squirrel-cage induction motor.

when a polyphase supply is not available. They are usually operated from lighting circuits and therefore most central stations limit the size to about 5 hp.

157. Synchronous Motors. These motors are constructed essentially like a.c. generators and require direct current to excite the fields. They are always operated from polyphase systems. Fig. 83 shows the arrangement for a three-phase motor. The motors must either be supplied with a separate starting motor or else special devices must be provided to make

* See paragraph 159.

them self-starting. In either case it is not possible to use them where heavy loads must be started. Synchronous motors must run at a constant speed, which is fixed by the number of poles and the frequency of the power supply. These motors are chiefly used for driving large, slow-speed air compressors, for motor generator sets and for large centrifugal pumps and blowers. The power factor of a synchronous motor may be changed by varying the field strength. By producing a leading power factor* in the synchronous motor, it is possible to neutralize the lagging power factor produced by induction motors connected to the same system.

158. Single-phase Series Motors. These a.c. motors have a series field winding and an armature with a commutator and brushes and are in many respects similar to d.c. series motors except for certain modifications in construction to adapt them for use with alternating current. Motors of this type are chiefly used for railway work. The characteristics are very nearly the same as those of d.c. series motors.

159. Other Types of A.C. Commutator Motors. The poor starting performance of the ordinary single-phase induction motor † has led to the development of a number of different types of single-phase motors with commutators designed to improve the starting performance. A type made by several manufacturers uses a single-phase stator winding with a rotor built somewhat like a d.c. armature with a commutator. By means of short-circuited brushes, located at proper points on the commutator, a starting effect is produced which is sufficient to start a heavy load. Fig. 84 shows the arrangement. After the motor has reached nearly full speed, a centrifugal device short-circuits the commutator bars, lifts the brushes off the commutator, and the machine then operates like an ordinary induction motor. The motor runs at practically constant speed. Motors of this type will start under full load with from 1.5 to 1.25 times full-load current taken from the line. The power factor, under starting conditions, is rather low. A modified type of this motor made by the Wagner Company (Type BK) gives a higher power factor both starting and running. The rotor contains a starting winding with commutator and a short-circuited (squirrel cage) winding, used when running. In this machine, the commutator bars are not

* See paragraph 323. † Paragraph 156.

short-circuited when running at normal speed, as current is taken from the commutator and passed through an auxiliary winding on the field in order to improve the power factor. Fig. 85 shows the connections of this motor. It is a constant-speed device. A somewhat similar motor is made by the General Electric Company and is called Type RI (Fig. 86).

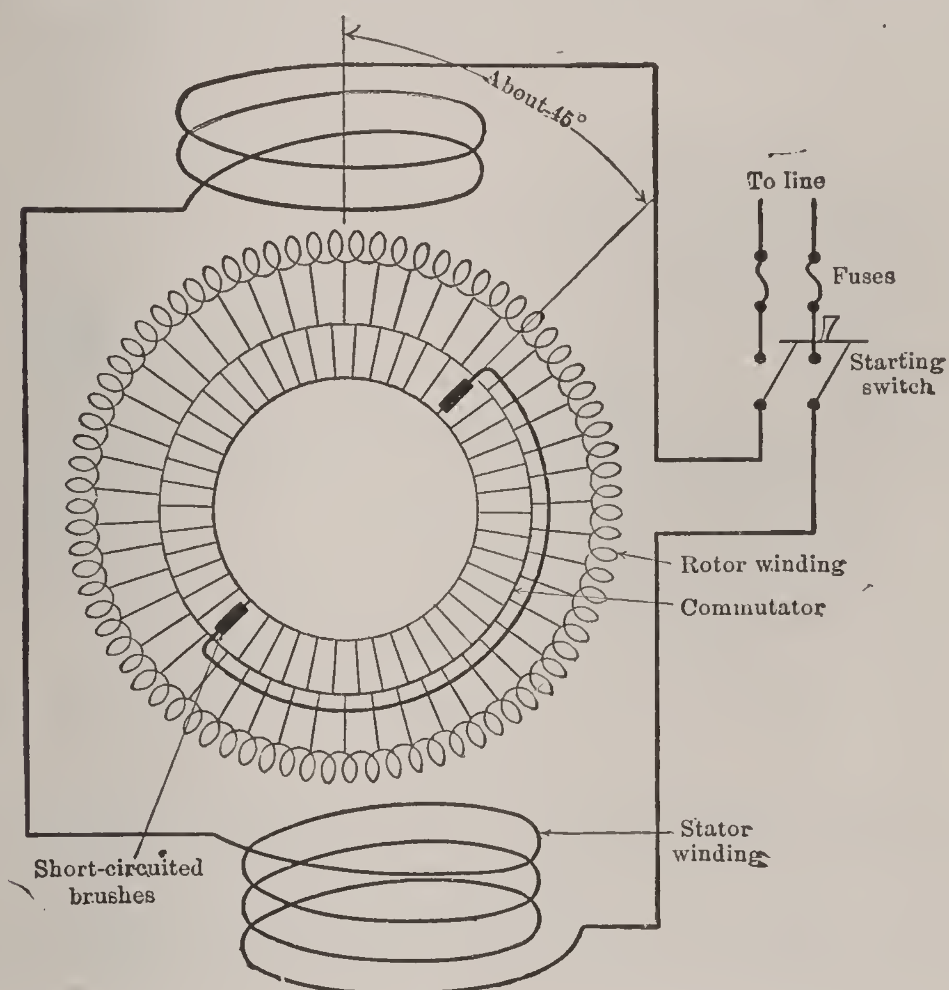


FIG. 84.—Diagram of Connections for a Single-phase Repulsion Motor. (Two-pole.)

The rotor has only a single winding, connected to a commutator. There are two sets of brushes, the "energy" brushes (3 and 4), which are short-circuited, and the "compensating" brushes (5 and 7), which are connected to the compensating winding. With small motors and all two-pole motors, there is only one set of energy brushes, as shown in Fig. 86. For larger four- and six-pole motors, there are two sets. The speed changes with load about like a compound motor with

a small series field. Motors of this type are also made for reversible service. For this purpose, a reversing winding is provided which produces the same effect as shifting the brushes. A varying speed type is also made. The speed is changed by shifting the brushes. Adjustable-speed motors giving a 2 to 1 speed range are also available. Type RI motors are made in sizes up to 15 hp. for constant-speed service and up to 5 hp. for varying-speed and adjustable-speed service. Com-

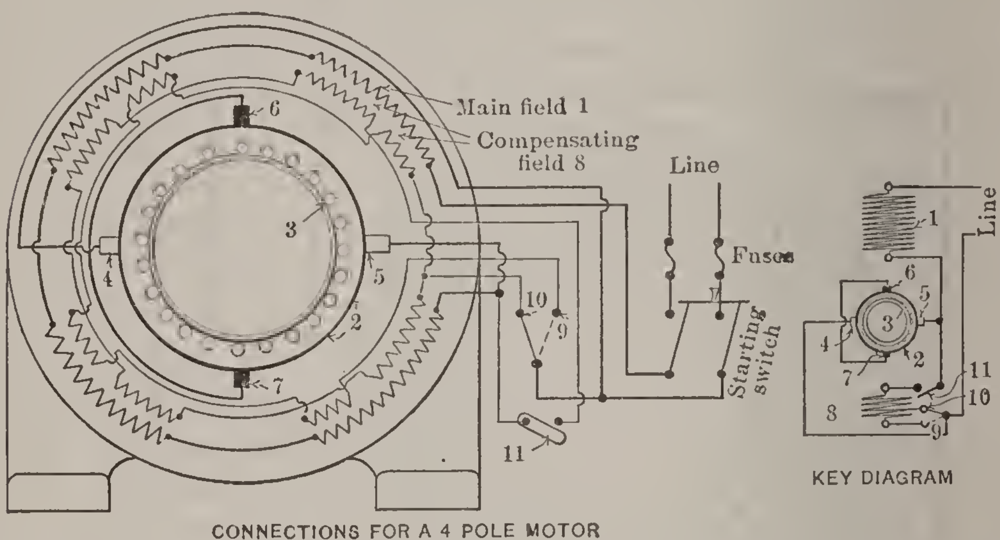


Fig. 85.—Connections for a Wagner, Unity Power Factor Motor. Type BK.

The stator has a main field winding (1) and compensating winding (8) on each pole. The rotor has a squirrel-cage winding (3) and drum winding with commutator (2). Main brushes (6) and (7) are short-circuited. Auxiliary or exciting brushes (4) and (5) supply current to compensating winding when switch (11) is closed. This switch closes by a centrifugal device when motor is nearly up to speed. With lead connected to (9), the maximum compensation is secured. giving a leading power factor at light loads. If lead is connected to (10), normal compensation is produced, giving a slightly lagging power factor at light load.

mutator type induction motors have already been described in paragraph 155.

160. Applications of A.C. Motors. The applications for which the various types of a.c. motors are best adapted are indicated in the tabulation following. In many cases they may be used for the same purposes as d.c. motors, the kind chosen depending upon the power supply available. For industrial applications either three-phase or two-phase induction motors are usually employed, synchronous motors being used only in large sizes and special applications, and the various single-

phase motors being used in small sizes where only single-phase power is available.

161. Vertical Motors. While motors arranged for mounting with the shaft vertical can be obtained in various sizes, they are to be avoided whenever possible. These motors require some kind of a thrust bearing to carry the weight of the armature, and this bearing is more likely to get out of order than the

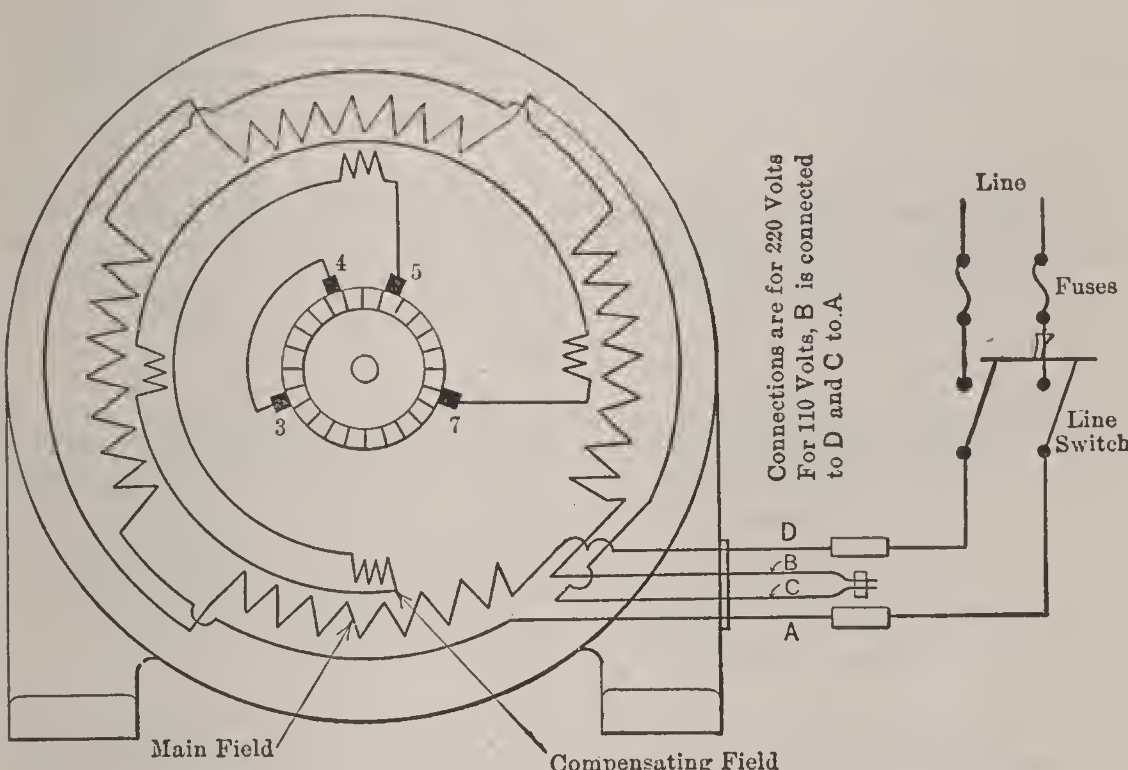


FIG. 86.—Connections for a Compensated Repulsion Motor. Type RI.

The figure shows a four-pole motor. Direction of rotation is changed by shifting the brushes to the other running mark on the brush-holder yoke.

bearings of horizontal motors. Vertical motors and their repair parts are usually not kept in stock by local dealers, so that repairs may be delayed by the necessity of ordering from the manufacturer.

162. Comparison of A.C. and D.C. Motors. It will be seen from the foregoing brief descriptions of the various types of motors that the usual power applications can be met by either a.c. or d.c. motors. There are, however, certain advantages and objections for each class. For supplying power to large areas, an a.c. system has many advantages, because a high voltage may be used to transmit the power, while by means of

PERFORMANCE OF A.C. MOTORS [1]

Type.	Starting Torque.	Running Performance.	Applications.
(1) Two or three-phase. Squirrel cage (low slip).	Relatively low. Starting current high.	Speed nearly constant. About 3 to 6% drop from no load to full load. Speed not adjustable.	Small blowers, cement and steel mills, screw machines, lathes, drills, pumps, conveyors, wood-working machinery.
(2) Squirrel cage (high slip).	Higher than for (1). Starting current less.	Speed decreases rapidly with load, somewhat like compound, d.c. motor.	Small cranes and elevators, punches and shears, large band saws.
(3) Slip-ring.	Higher than (1) and (2). Starting current small.	With starting resistance out, acts like (1). With resistance in circuit, speed can be adjusted to any desired value at a sacrifice in efficiency.	Elevators, cranes, air compressors, ventilating fans, steel mills, hoists, wood-working machinery.
(4) Single-phase (split-phase).	Low starting torque. Large starting current.	Similar to (1).	Used only in small sizes. Employed for constant speed applications only, such as small printing presses, sewing mach., etc.
(5) Single-phase (repulsion).	Fairly high starting torque, but not as good as polyphase motors.	Similar to (1).	For constant speed applications. Used principally in sizes below 15 hp. where only single-phase service is available.
(6) Synchronous.	Low starting torque, large current.	Speed constant and cannot be adjusted.	Large air compressors, line shafts, pumps.

[1] See also paragraph 188.

transformers a lower voltage may be used for the motors. This reduces greatly the cost of the feeder system. A comparison of a.c. and d.c. motors is given in the following tabulation:

COMPARISON OF MOTORS

Direct Current.	Alternating Current.
1. Voltage limited to about 240 volts, if same source is used for lighting.	1. The voltage can be easily transformed, using voltages suitable for lamps and motors.
2. Maintenance higher, owing to commutators.	2. Absence of commutator makes motor more rugged. It will stand larger momentray overloads, there is no danger of fire from sparks from commutator and it is more reliable.
3. Wide speed adjustment by simple means, with high efficiency.	3. Speed adjustment is difficult and motor is less efficient at reduced speeds.
4. Motors have better starting performance for cranes and elevators.	4. Operation is not satisfactory on high-speed elevators and large cranes. Starting current is greater.
5. Starting current is lower for usual types of constant-speed motors.	5. Starting current for ordinary type is large. Special arrangements necessary to reduce it.
	6. A somewhat larger generator is required for a given motor load.

In general it may be said that, for industrial purposes, there is no need of using d.c. motors except for adjustable-speed service for machine tools; for varying-speed service, such as cranes, hoists, etc., and for service requiring frequent starting and stopping of heavy loads, as in high-speed elevators. The greater reliability and ruggedness of the a.c. induction motor makes its use generally preferable for other purposes. The squirrel-cage induction motor, having no commutator or slip-rings, can be operated, without enclosing the frame, in very dusty or dirty places or in rooms where there would be danger of explosion from a spark, such as flour mills and grain eleva-

tors. If d.c. motors are used in such places, they must be carefully enclosed, and this increases the heating and reduces their safe output. With standard squirrel-cage induction motors (either two-phase or three-phase) it is possible to obtain a torque * at starting which is from 1.5 to 2.0 times the torque required at full load and with slip-ring motors from 2.5 to 3.5 times this torque may be obtained. This meets the ordinary requirements. Where motors are used in a plant which covers a wide area, it is generally customary to provide direct current only for the tools requiring this system and to use alternating current for all constant-speed service, thus saving in the cost of the feeder system. The direct current would be furnished by a motor-generator set driven from the a.c. supply and located conveniently near the d.c. load.

163. Standard Voltages. For d.c. motors, the standard voltages are 115, 230, or 550, and for **a.c. motors**, 110, 220, 440 and 550 volts are commonly employed, although in some cases, for very large motors, 2200 volts are used. The voltages given are the values at the motors. The generator voltages are about 10 per cent higher to allow for the loss in the wiring.† D.c. motors smaller than 0.5 hp. should preferably be operated at 115 volts. For industrial purposes, 110-volt induction motors are seldom used, the common voltages being 220 or 440 volts. A voltage of 550 has also been used to some extent. In general, 220 volts is preferable for moderate-sized installations, particularly where the supervision may be in relatively unskilled hands. The danger of workmen receiving fatal shocks is greater with alternating than with direct current, and at 440 or 550 volts this presents a real hazard; a shock from 220 volts is seldom fatal. In establishments of considerable size, particularly with large motors, the great saving in feeder size with 440 or 550 volts results in their frequent use. More complete protection is possible with alternating than with direct current, so that with careful planning of the control devices and first-class wiring, these higher-voltage systems can be made fairly safe. Sometimes 1100 or 2200 volts are used for a.c. motor drives, but such high voltages are adapted only for large motors and require special methods of installation of the wiring and control system to

* That is the force tending to rotate the armature.

† See paragraph 317.

make them safe. The voltage of motors for driving machine tools has been standardized at 110 or 220 volts.

164. Frequency. The standard frequencies for a.c. motors are 25 and 60 cycles, while 40-cycle motors are used to a limited extent. In general, 60 cycles is the best frequency because of the greater number of available speeds. A.c. motors have definite speeds, fixed by the frequency and depending upon the number of poles, whereas d.c. motors have greater flexibility in this respect. The available no-load speeds for a.c. motors for the usual range are given below:

AVAILABLE SPEEDS FOR A.C. MOTORS

Number of Poles.	No-load Speed, R.P.M.	
	60 Cycles.	25 Cycles.
2	3600	1500
4	1800	750
6	1200	500
8	900	375
10	720	300
12	600	250
14	514	214

The highest speed is for the two-pole motor, and the speed can be made as low as required by providing a suitable number of poles. It will be seen by reference to this table that, for 25 cycles, motors can be built for only three speeds between 500 r.p.m. and the maximum; whereas for 60 cycles there are seven speeds. All of these speeds cannot be obtained from the same motor, which, on the contrary, must be built for a particular speed, and only by special design can it be run at more than one of these speeds.* For high-speed motors, the cost of 25-cycle motors for approximately the same speed is from 5 to 20 per cent more than 60-cycle motors, and the 25-cycle motors are heavier. For very large, slow-speed service (such as rolling mills, air compressors, etc.), 25-cycle motors are better, because they are cheaper and more efficient.

* See paragraph 154.

165. Rating and Overload Capacity. Motors are rated at the normal output in horsepower which they will deliver under specified conditions. Recently attempts have been made to rate motors in kilowatts output, but the horsepower rating is still used by manufacturers. The rating in kilowatts (kw.) can be determined by multiplying the horsepower rating by 0.746. The horsepower rating can be determined by multiplying the kilowatt rating by 1.34. The rating does not of course give the total input to the motor, because of the losses, so the kilowatt output must be divided by the efficiency of the motor to obtain the power input. The rated output of a motor is always marked on the manufacturer's nameplate, together with the voltage, full-load current, speed, and frequency if an a.c. motor. The horsepower rating given on a nameplate indicates the load which the motor will carry either continuously or for a short time, depending upon the service for which the motor is designed. In all cases the load which the motor can carry is limited either by the heating of the windings or by sparking at the commutator. All motors will carry much greater loads than their rating. If a steam or gasoline engine is too heavily loaded, it will stop, without, however, doing any damage to the machine. If a very heavy load is placed on an electric motor, it will also stop, but before this happens the current will become so large that the motor will burn out. An electric motor therefore cannot adjust itself to take only a safe load, but must be protected against overloads by fuses or circuit-breakers. Consequently the output of a motor or its rating is given as the horsepower which the machine will carry without exceeding a safe temperature or without appreciable sparking at the commutator. It is apparent that the load which a motor can carry for a short time is larger than the continuous-load capacity of the motor. Accordingly, when the horsepower of a motor is given, it must be stated whether this load can be carried continuously or only for a short time. **For continuous duty** the motor must carry its rated load continuously without exceeding certain specified temperatures (see Table 20). Unless the name plate definitely states otherwise, motors are always assumed to be for continuous duty. **For short-time duty** the motor must carry its rated load for definite periods of time, for example one-half hour, with periods of rest between operating periods, sufficient to allow the motor to cool off. Motors

for cranes operate under these conditions. In Table 20 is given the operating conditions for various kinds of standard motors. The temperatures are given in degrees rise in temperature above the surrounding air. For example, if a 40° Cent. rise is given and the room temperature is 25° Cent., this would make the temperature of the winding 65° Cent. (149° Fahr.). If, however, the room temperature is 35° Cent., the rise in temperature would be nearly the same and the actual temperature of the winding would become 75° Cent. Damage to the insulation of the machine, however, is caused by the actual temperature which the windings reach, and therefore, if the room temperature is likely to be high, care must be taken to select a motor of ample size and thus keep the operating temperature down to a safe value. In general, the temperature of the windings should not exceed 90° Cent. as measured by a thermometer placed on the windings and properly protected. Thus, if the room temperature was 35° Cent. (95° Fahr.) a motor carrying 25 per cent overload might reach a temperature of 90° Cent., and it would probably be best to select a motor somewhat larger, so that it would not run too close to the limiting temperature. The temperature ratings also depend upon the kind of motor, whether open or enclosed. This is indicated in Table 20. While motors rated for continuous duty can carry a sustained overload of 25 per cent for a definite length of time (one-half hour or more), they will carry much larger overloads for a few minutes. In such cases, the heating effect is not important, and the limit, in the case of d.c. motors, is fixed by the sparking at the commutator. By the use of interpoles, the commutation of modern d.c. motors has been greatly improved so that momentary overloads of 50 to 75 per cent may be carried. The standard overload rating is, however, 50 per cent, except in the case of small motors (see Table 20). Three-phase and two-phase induction motors do not have commutator troubles, but they are also limited in the amount of overload they can carry. If the load on an induction motor exceeds a certain amount, the motor will "pull out" and stop and will take a very heavy current. For commercial motors, a load of from 2.5 to 3.5 times full load can be carried without the motor "pulling out" and stopping. Synchronous motors will carry a load of from 1.5 to 2.0 times full load without stopping.

166. Open and Enclosed Motors. Since the output of a motor is usually limited by the heating, it is apparent that the various parts should be as freely ventilated as possible. In many cases, however, it is necessary to enclose the windings to protect them against mechanical injury, excessive dust or, in some cases, to prevent communicating fire to inflammable materials. Motors for industrial purposes are therefore classified according to the amount of such protection that is provided. While there are a number of different classes, they may all be grouped as either open, semi-enclosed or enclosed motors. In the **open motor** the windings and rotating parts are freely exposed to a circulation of air, which serves to cool the windings. This type gives the best ventilation possible, and therefore for a given load will be the cheapest type of motor to use. The open type would therefore always be selected where the conditions permit, that is, where dust or moisture are not excessive. Where there is considerable dust or dirt, motor bearings are sometimes made dust proof by the addition of felt rings at each end. **The semi-enclosed motor** is similar to the open type except that the openings at each end of the frame are covered by gratings or screens, which allow a fairly free ventilation, but protect the motor against damage from pieces of wood, metal, or other substances which might be dropped into it. This arrangement does not protect the motor against fine dust which could pass through the openings. A semi-enclosed motor will run slightly hotter than an open motor, since the covers shut off some of the air circulation. **The enclosed motor** has solid covers closing all openings to the inside of the machine. Such a motor is practically dust and moisture proof. These motors are used for very severe operating conditions, where there is a large amount of dust or where considerable moisture is present. When d.c. motors are installed where inflammable dust exists, the enclosed type is necessary. When a motor is enclosed in this way there is no free circulation of air over the various parts of the windings and the entire cooling of the motor must be accomplished by cooling the outside frame of the machine. A given size of motor would therefore run much hotter if enclosed than if open. Stated another way, to carry a given load the motor must be much larger if enclosed. To partly offset this difference, enclosed motors are allowed to run somewhat hotter than open

motors, as will be seen from Table 20. An enclosed motor is from 25 to 40 per cent heavier than an open motor and is therefore correspondingly more expensive. In some cases, particularly with large enclosed motors, air is blown into the motor by means of a blower to assist in the cooling.

Motor Performance

167. Motor Currents. The full-load current taken by shunt or compound motors is given in Table 21. This table can also be used without great error for series motors. For three-phase and two-phase induction motors, Tables 22 and 23 may be used. The values of current given in the tables take into account the efficiency of the motor and in the case of induction motors also include the power factor. The values at other loads can be approximately determined by multiplying by the given load. Thus a 50-hp., 230-volt, d.c. motor operating at three-quarters load would require a current of approximately $0.75 \times 178 = 134$ amperes. This method is not accurate at light loads since the efficiency under such conditions is much lower. While the tables give the full-load current for squirrel-cage induction motors, the same values may be used for slip-ring motors without much error. To determine the current for a motor not given in the tables, find the amperes per horsepower for the next smallest motor and then multiply by the horsepower of the given motor.

Example. Find current for a 65-hp., 550-volt, d.c. motor. From Table 20 the full-load current of a 60-hp. motor is 89.5 amperes.

$$\text{Amperes per hp.} = \frac{89.5}{60} = 1.49.$$

Full-load current for a 65-hp. motor is $1.49 \times 65 = 97$ amperes.

The comparative **starting current** required by different types of motors is indicated in the following tabulation. There is, however, considerable variation in this respect for different designs.

COMPARISON OF STARTING CURRENTS FOR MOTORS

Type of Motor.	Current Compared with Full-load Running Current.	
	For Full-load Torque.	For 50% Overload Torque.
Series	1.0	1.3–1.4
Shunt	1.0	1.5
Compound [1]	1.0	1.45
Squirrel-cage induction [2] (low slip)	2.5–3.0	5.7
Slip-ring induction	1.0	1.5

[1] For a motor with 27 per cent series field.
[2] Current taken from line, using auto-starter.

The starting current for compound motors depends upon the strength of the series field. The value given in the table is for a rather weak field, such as would be used for planers, etc. It is possible to build squirrel-cage motors which will take only slightly more current than the slip-ring motor, but such a machine would have a poorer efficiency and wide speed variations with changes in load. The starting current of a synchronous motor depends upon the service for which it is designed. A starting torque of about 25 per cent of full-load torque can be obtained with 1.75 times full-load current, requiring about one-half normal voltage. This torque is sufficient for the usual starting requirements. Single-phase induction motors which are started by a set of short-circuited brushes * require about 1.25 to 1.5 times full-load current for full-load torque. The Wagner Type BK motor requires about 2.0 times full-load current for full-load torque. The General Electric RI motor requires about 2.25 times full-load current.

168. Power Factor of A.C. Motors. † With a.c. motors the power factor must be taken into account. That is, the actual power taken by the motor is not the same as the power calculated from the volts and amperes, but is usually less. Thus a three-phase, 50-hp., 440-volt induction motor requires 61 amperes at full load. The apparent power taken from the line

* See paragraph 159. † See paragraph 323.

is therefore $440 \times 61 \times 1.73 = 46,400$ volt-amperes. But since the power factor of this motor is 0.89, the actual power taken from the line would be $0.89 \times 46,400 = 41,300$ watts or 41.3 kw. The power factors of induction motors when running at three-quarters or full load are given in Table 24. At no load, the power factor is very low for all sizes of motors, being about 0.30. For the usual operating loads, however, the power factor is not less than 0.80 to 0.85. These values apply to squirrel-cage or slip-ring induction motors, whether three-phase or two-phase. When starting full load, the squirrel-cage motor has a power factor of about 0.50. The slip-ring motor has a much higher power factor at starting. It is practically the same as the running power factor for the same current input. The power factor of a synchronous motor, when running, can be changed by adjusting the field rheostat. When adjusted to a value of 1.0 the current taken by the motor is the smallest possible for the particular load carried. Weakening the field by cutting in more of the field rheostat will increase the current and give a lagging power factor, although the real power taken by the machine will not change unless the load changes. Strengthening the field, on the other hand, will also cause the current taken by the motor to increase and will at the same time give a leading power factor. Because of this action, the synchronous motor is sometimes adjusted to produce a leading power factor to correct the lagging power factor produced by induction motors connected to the same system. The power factor of a synchronous motor at starting is very low, being about 0.20.

169. Effect of Change in Voltage. With d.c. series motors, the speed for a given current depends upon the voltage. Hence a 10 per cent increase in voltage would result in a speed increase of 10 per cent if the current remained the same. If the load increased faster than the voltage the speed increase would be less than 10 per cent. With shunt motors a moderate change in the voltage applied to the motor has very little effect upon the speed. The compound motor usually acts in somewhat the same way as the shunt motor. The speed of an induction motor varies only slightly with moderate changes of line voltage, but the maximum load which the motor can carry is affected greatly by the voltage. As the maximum torque varies with the square of the voltage, small changes in voltage

produce large changes in torque. Thus a squirrel-cage induction motor giving, at normal voltage, a maximum torque 2.5 times full-load torque would if the voltage dropped 20 per cent have a torque only 1.6 times* full-load value, and hence might stall on an overload. The speed of synchronous motors is not affected by changes in voltage, but the torque is affected similarly to induction motors. In general a voltage variation of 10 per cent above or below normal will not interfere with satisfactory operation.

170. Effect of Change in Frequency. The speed of **induction motors** depends upon the frequency. If the frequency is increased 10 per cent, the speed will increase 10 per cent, and the opposite effect occurs for a decrease in frequency. This assumes that the load on the motor does not change. Induction motors will usually operate satisfactorily with a frequency variation of not more than 10 per cent above or below normal. **Synchronous motors** maintain absolutely constant speed as long as the frequency is constant, and hence the speed depends upon the frequency, regardless of the load.

* $0.80 \times 0.80 \times 2.5 = 1.6$.

CHAPTER 10

MOTOR-STARTING DEVICES AND CONTROLLERS

Starting Methods

171. D.C. Motors. Small d.c. motors (up to $\frac{3}{4}$ hp. for shunt and 5 to 8 hp. for series) may be thrown directly upon the line without injury. For larger motors, a resistance must be placed in the armature circuit to limit the starting current to a safe value because of the low resistance of the motor armature. For example, a 25-hp., 230-volt, shunt-wound motor would require a full-load current of about 91 amperes. The resistance of the armature would be about 0.10 ohm. Hence, if the armature was connected directly to the line without a starting resistance, the current would be $230 \div 0.10 = 2300$ amperes or over 25 times full-load current. The starting resistance is usually arranged to allow about 1.5 times full-load current to flow when the motor is first thrown on the line. For severe starting service, such as cranes and elevators, a larger starting current may be allowed. In all cases the field strength at starting should be as large as possible to give the maximum torque for the current used. With shunt and compound motors, therefore, the shunt field winding is always connected directly to the line without any resistance in circuit. The position of the starting resistance would be as shown in Figs. 73 and 75. As soon as the motor starts, the current taken decreases and the starting resistance must be reduced. D.c. motor starters are therefore arranged to cut the resistance out in several steps as the motor speeds up, until finally all the resistance is out and the motor armature is directly across the line.

172. A.C. Motors. Small squirrel-cage induction motors (up to 5 or 8 hp.) may be started by throwing them directly on the line. The current which the motor takes when this is done is not as great as for d.c. motors, being from five to eight times full-load current. Motors as large as 50 hp. might be

started in this way without damage to the motor. The heavy current required would, however, cause a very large voltage drop in the feeders and frequently serious disturbance of the generator voltage. For starting small squirrel-cage induction motors, resistance starters (Fig. 99) are sometimes used, but the auto-starter or compensator (Figs. 97 and 98) is usually employed. A star-delta method of starting is also employed to some extent (Fig. 101). **Slip-ring motors** are started by inserting a resistance in the rotor circuit (Figs. 80 and 100).

173. Auxiliary Apparatus. All motors must be provided with a switch to disconnect the motor from the line and with fuses or a circuit-breaker, to protect the motor in case of heavy overloads. These devices are described in Part III.

174. Rating of Starters. Starters are rated according to the sizes of motors for which they are designed. A different starter is required for different voltages and sizes of motors. With d.c. motors, if the starter is too large, the current taken by the motor will be excessive; if too small, the motor may not start and the starter may be burned out. If a small auto-starter is used with a large a.c. motor, the starter will be overloaded and probably damaged. Ordinary starters are intended for occasional use only and do not have sufficient capacity to carry the starting current continuously or to start the motor at very frequent intervals. If the resistance is to be left in the circuit for adjusting the speed as shown in Fig. 72, the rheostat is called a **speed regulator.**

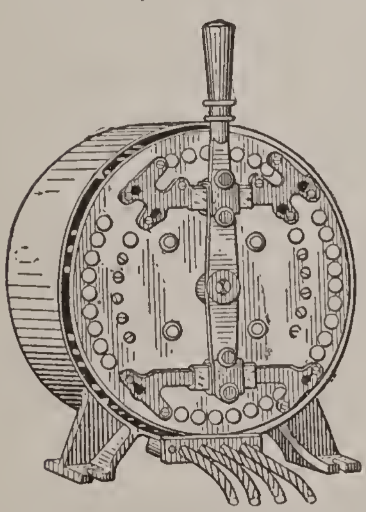


Fig. 87.—Starter for Series Motor.

Small crane or hoist controller.

D.C. Starting Rheostats

175. Starters for Series Motors. For motors which are to be started only at fairly long intervals, a starter with no-voltage release, similar to that described in paragraph 176, is used. Where motors are to be frequently started, stopped and reversed, as in crane service, either face-plate starters (Fig. 87) or drum controllers (Fig. 93) are used. The motor is reversed and brought up to speed by movements of a single handle.

176. Starters for Shunt and Compound Motors. The simplest form of starter for these motors is the hand-operated face-plate starter (Fig. 88). This includes a suitable starting resistance, so connected that it may be short-circuited by a contact arm as the motor is brought up to speed. This type of starter is used for motors up to about 50 hp. For large motors, the multi-switch type (paragraph 177) is used. In Fig. 88 a face-plate starter is shown connected to a compound motor. The same type of starter can be used for shunt or series motors. These starters are provided with a **low-voltage release.** This consists of an electro-magnet which holds the rheostat arm in

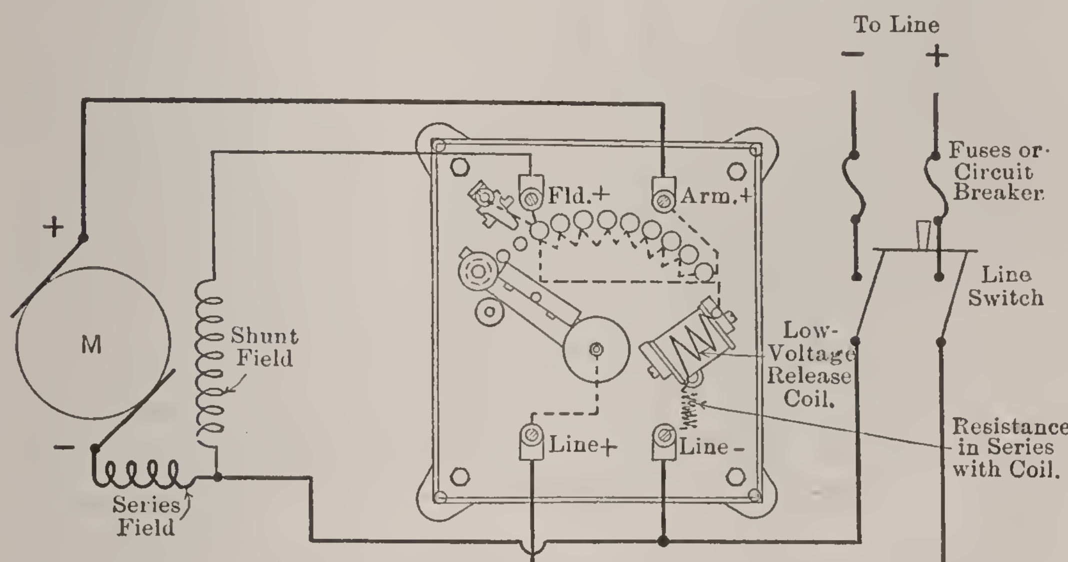


FIG. 88.—Connections of Starter for Shunt and Compound Motors. With low-voltage release.

the running position as long as there is voltage on the motor circuit. In case of a failure of the line voltage, the magnet releases this arm and it is returned to the off position by a spiral spring. Hence the motor will not be damaged if the voltage is thrown on again. The magnet does not release until the motor has slowed down, because, for a short time, the motor acts as a generator and keeps the magnet energized. The low-voltage release magnet is either connected directly across the line (as in Fig. 88) or is placed in series with the shunt field winding. When connected across the line, the strength of the magnet is independent of the current in the motor field. If connected in series with the shunt field, the magnet might become so weak (due to weakening the shunt field) that it could not hold the arm

in the running position. If the magnet is in the field circuit, however, it will release and stop the motor if the field circuit is opened, whereas if connected across the line it would not release and the motor might run away. Usually in such cases there is sufficient load on the motor to prevent it from running away and the heavy current taken by the motor would be sufficient to open the circuit breaker or blow the fuses. Starters of this type are frequently equipped with an **overload release.** This consists of a coil in series with the armature which operates similarly to a circuit breaker. Fig. 89 shows a starter with overload and no-voltage release as made by one manufacturer. The overload release is only used on comparatively small motors (up to about 15 hp.). For larger motors, separate circuit breakers are used. For many industrial plants, particularly where there is considerable dust or where it is desirable to protect the operators against possibility of an electric shock, the starters are enclosed in metal boxes. The face-plate type of starter is used where the motor is started only occasionally. In machine tool service, etc., the drum type controller* is more satisfactory because it will withstand harder usage.

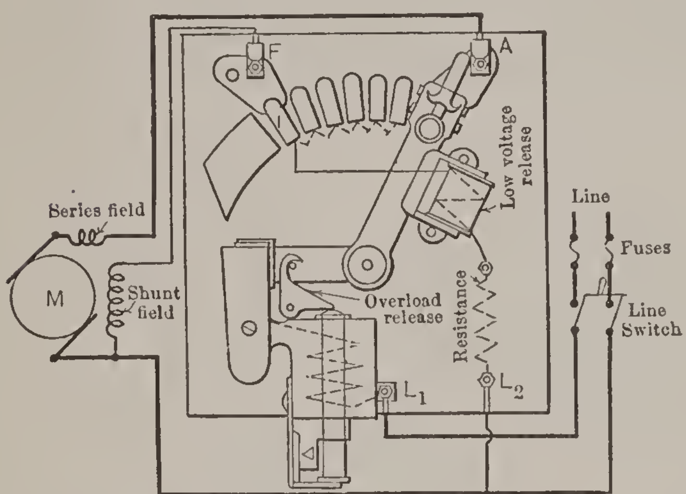


FIG. 89.—Connections of Starter for D. C. Motors. With overload and low-voltage release.

Connections shown are for a compound motor. For a shunt motor, *A* is connected directly to armature. For a series motor, connection to *F* is omitted. When arm is on the starting-point (1), the motor receives full field. As the armature resistance is cut out by moving arm to the right, this resistance is cut into field circuit. The value of this resistance is so low, however, compared with that of the field, that it has no effect upon the speed of the motor.

177. Multiple-switch Starters. The face-plate starters described in the previous paragraph are not suitable for large currents because of difficulties with the contacts. The multiple-switch starters, which are used for large motors, consist of a

* See paragraph 180.

number of switches each short-circuiting a section of the starting resistance. The general arrangement of a multiple-switch starter is shown in Fig. 90 and the connections in Fig. 91. The switches are mechanically interlocked so that they must be closed in regular order, corresponding to the movement of the arm of the face-plate starter. One of the switches acts as a circuit breaker and is provided with a **low-voltage release** which acts in the manner already described. This

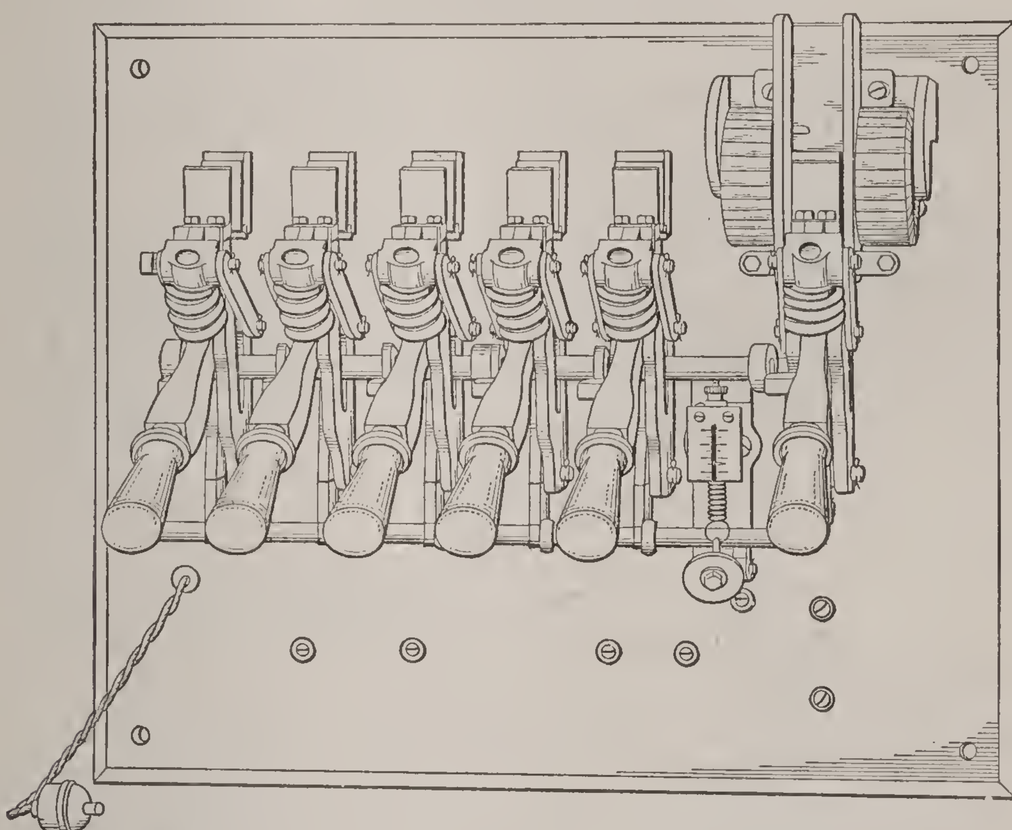


FIG. 90.—Multiple Switch Starter.
For large d.c. motors.

switch is also provided with an **overload release** to protect the motor.

178. Speed Regulators. When the speed of a motor is to be adjusted by an armature resistance (Figs. 72 or 74*b*), a rheostat somewhat similar to that shown in Fig. 88 is used, except that provision must be made to hold the arm on any one of the contact buttons. To comply with the Code rules, this arm must have a **low-voltage release**, to stop the motor if the voltage fails. An **overload release** is also used in some cases. If a

speed-regulator of this type is used, no additional starting rheostat is required. When the speed of a shunt or compound motor is adjusted by field control (Fig. 74*a*), a separate rheostat may be used. It must be of such a type that the field circuit is always kept closed, otherwise the motor would tend to run away. When a rheostat of this type is used, a starting rheostat must also be provided. This would be either of the

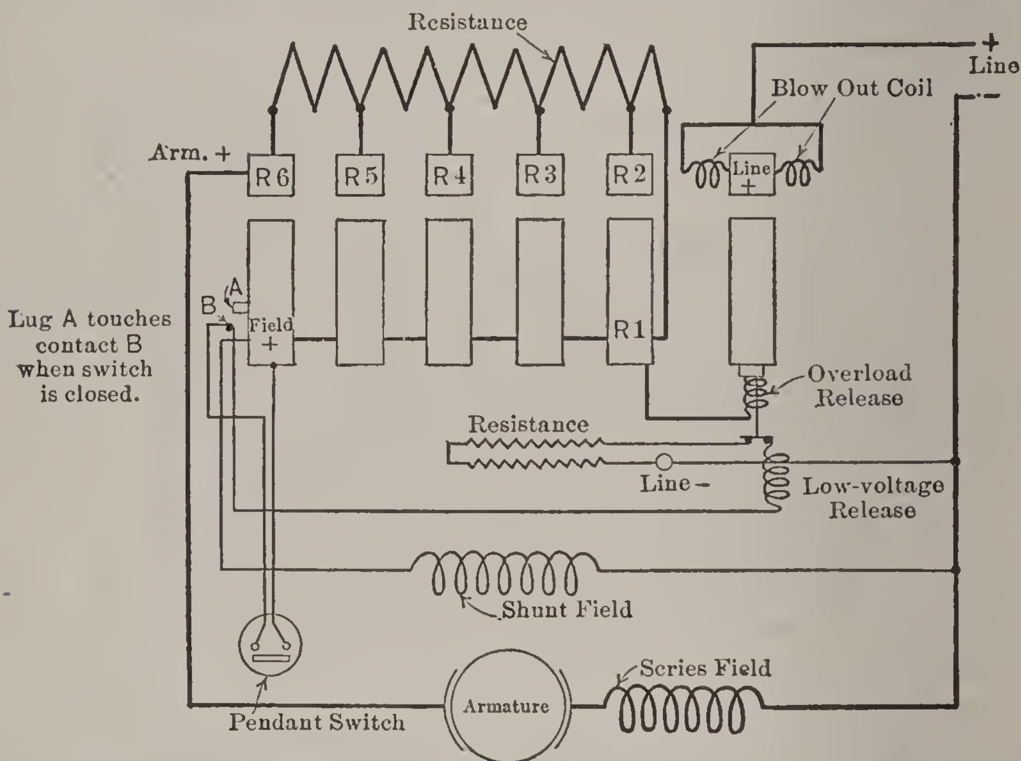


FIG. 91.—Connections for Multiple Switch Starter.

To start the motor, the line switch is closed, thus completing the circuit to the motor through the entire resistance. Switches *R*2, *R*3, etc., are closed in regular order, thus cutting out the starting resistance. These switches are mechanically interlocked, so they can only be closed in the proper order. The pendant switch must be held closed until *R*6 is closed, otherwise the low-voltage release relay will trip the line switch and open the circuit.

two types previously described. To ensure that the motor shall always be started with strong field* the starter is provided with a relay which short-circuits the field rheostat while the motor is being started. Generally the starting rheostat and the field rheostat are combined, forming a compound starter. Speed regulators are used principally on ventilating fans.

179. Compound starters are arranged to cut in the field resistance after the motor is up to speed (Fig. 92). Movement of the arm towards the running position first cuts out the starting

* For the reason given in paragraph 176. This is required by the Code.

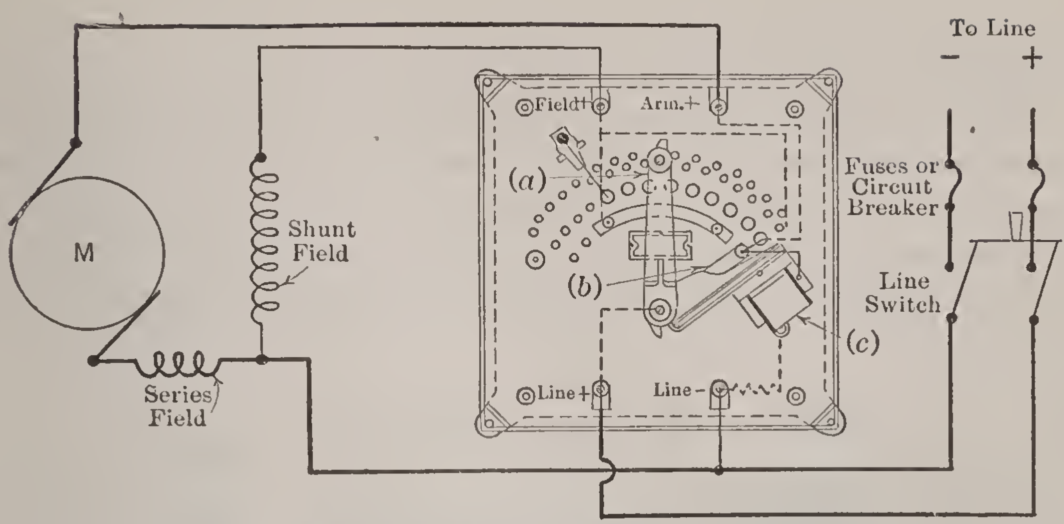


FIG. 92.—Connections for a Compound Starter. For starting and adjusting speed of shunt and compound motors.

The upper row of buttons is connected to the field resistance, the middle row to the armature. The curved segment below the buttons is used to short-circuit he field resistance when starting. There are two movable arms (*a*) and (*b*) pivoted to the same hub. These move together when the motor is being started. Arm (*a*) makes contact with both rows of buttons and (*b*) with the segment. When the arms have reached the running position (to the extreme right) arm (*a*) can be moved back, leaving (*b*) as shown. This inserts resistance in the field circuit. A low-voltage release coil (*c*) causes both (*a*) and (*b*) to return to the off position if the supply fails.

resistance with full field on the motor. After the starting resistance is all out, further movement of the arm inserts resistance in the shunt field. Figs. 93 and 94 show a controller of this type used for operation of machine tools.

180. Drum Controllers. For adjustable speed, shunt or compound motors operating machine tools, the drum controller is best (Figs. 93 and 94). This contains contacts for starting the motor and also contacts for inserting field resistance, as in compound starters. These controllers are also arranged to reverse the motor by a change in the direction of motion of the handle. They are used in capacities up to about 50 hp. For larger motors the controller operates electro-mag-

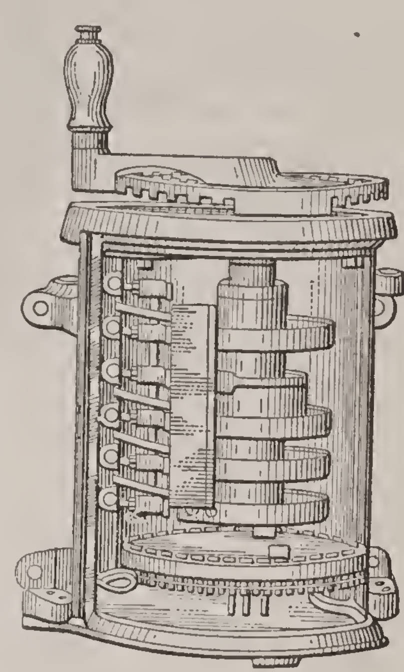


FIG. 93. — Machine-tool Controller. (Cover removed.)

With contacts for starting, reversing and adjusting speed by field control. 10-horsepower capacity.

netic switches, mounted separately, which make the necessary connections for starting.

181. Automatic Starters. The starters previously described are all hand operated, and in the hands of a careless workman may be so operated as to damage the motor by starting too quickly or to burn out the starter by running too long in the starting position. There are also cases where the motor must

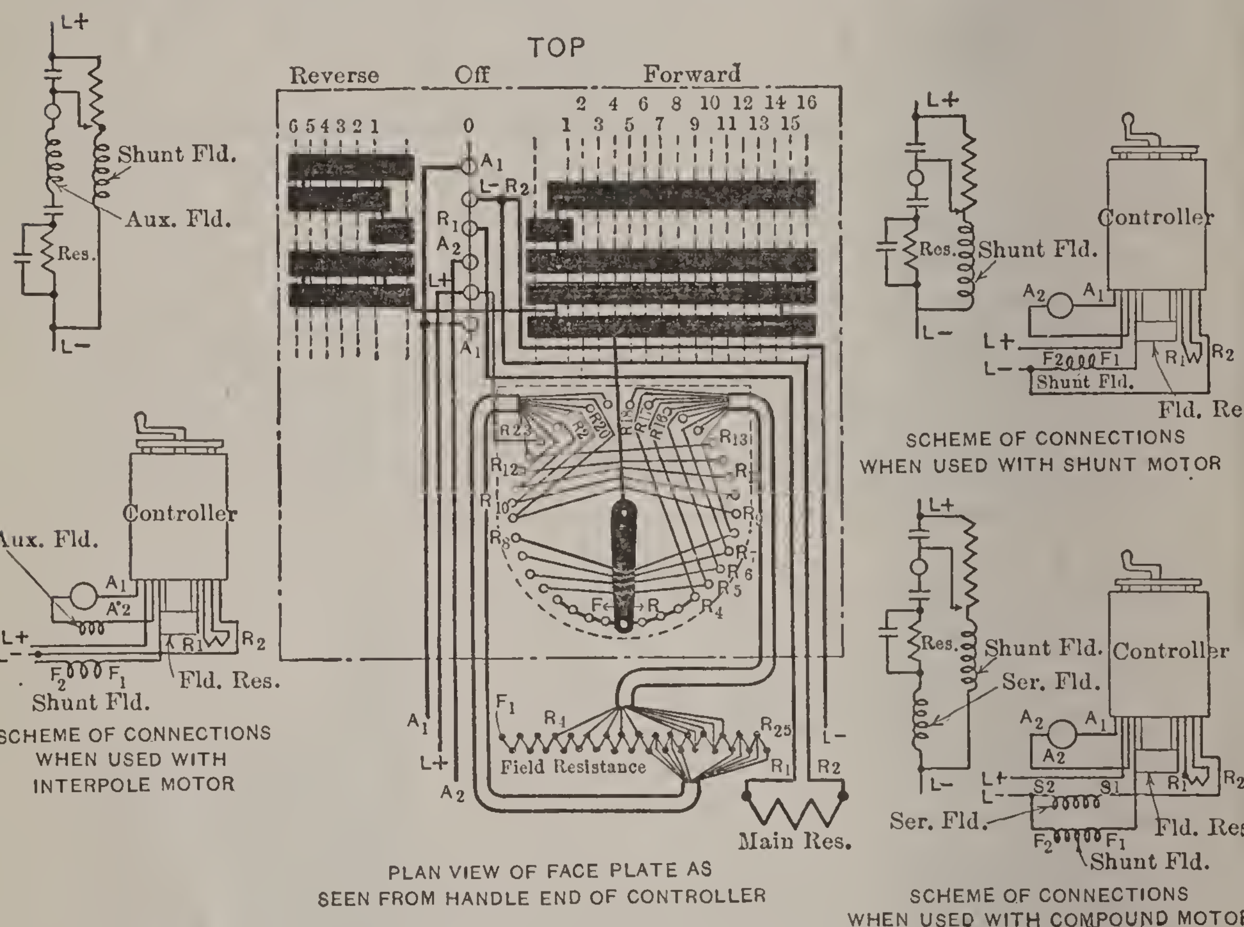


Fig. 94.—Connections of Machine-tool Controller, Shown in Fig. 93.

This controller has 16 running-points forward and 6 reverse. In addition there are two starting-points. (Westinghouse Electric & Mfg. Co.)

be started and stopped in response to changes in pressure, water level, etc. The simplest type of controller to meet these conditions is the dash-pot type (Fig. 95). The rheostat arm is moved by a solenoid magnet which is retarded by a dash pot, so the resistance will not be cut out too rapidly. This type of starter is used for small motors. It may be controlled by a switch or push buttons located at any convenient point or by means of a contact-making pressure gauge or a switch operated

by a float. For larger motors, it is usually necessary to employ a starter which will automatically limit the starting current to a safe value. While there are many arrangements to secure this result, the principle can be understood by reference to Fig. 96. The operation is controlled by push buttons. Closing the "start" button completes a circuit from the — line through 1, 10, 01, 0, *B*, back to the + line. This closes the line switch (No. 1), completing a circuit from the + line through

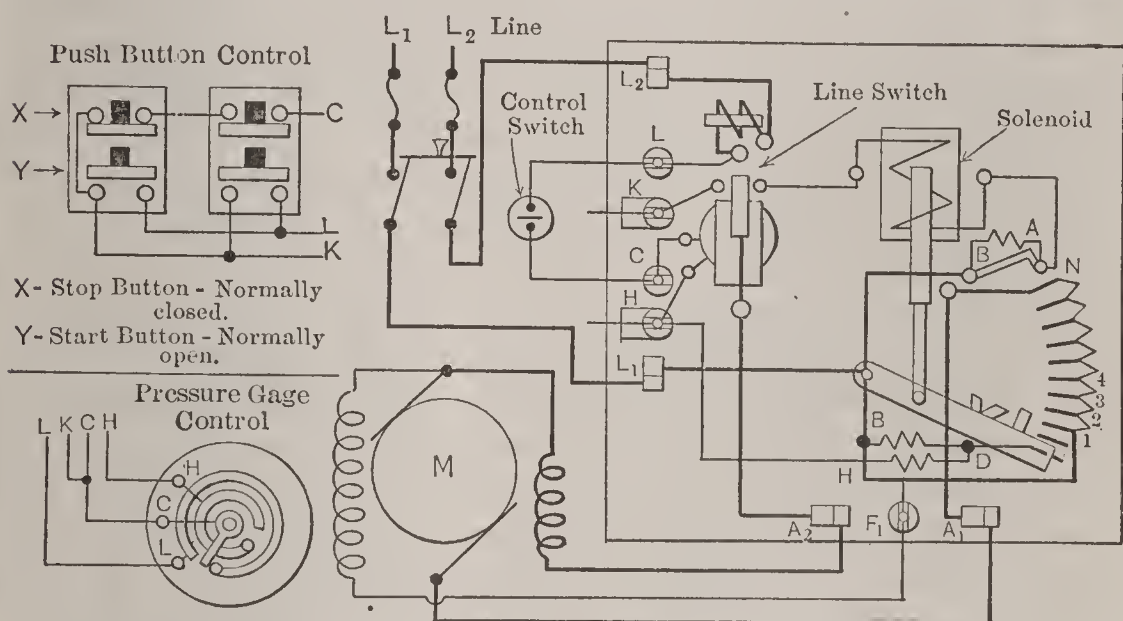


FIG. 95.—Automatic Starter. Dash-pot type.

When control switch is closed, line switch solenoid is energized through L_2, *L*, *C*, *H*, *D* to L_1. This closes line switch and motor is started with all resistance in. When the line switch closes, the auxiliary contacts close the main solenoid circuit from L_2 to *A* and thence to L_1. This causes the rheostat arm to rise slowly as controlled by the dash-pot and thereby cut out the resistance. As soon as the arm starts, the circuit through the line-switch solenoid becomes L_2, *L*, *C*, *H*, *D*, *B*, L_1, thus inserting additional resistance so as to reduce the current consumed by the solenoid. When all starting resistance is cut out, a contact brush on the movable arm makes a direct connection between L_1 and A_1. At the same time, additional resistance *A–B* is inserted in the solenoid circuit. Motor is stopped by opening control switch. In place of a simple control switch, either a push button or a pressure gauge may be used, with connections as shown in the auxiliary diagrams. (Cutler-Hammer Mfg. Co.)

B, *C*, R_3, R_2, R_1, A_1, S_2, to the — line. The closing of the line switch (No. 1) closes contacts 10 and 1, thus keeping a circuit through the operating coil of No. 1 even when the "start" button is released. The starting current passes through the operating coil of switch No. 2, which is so designed that it is locked open until this current drops to a predetermined value. Switch No. 2 then closes, thus short-circuiting resistance R_1–R_2. Switch No. 3 has an operating coil connected in shunt with the

armature terminals. The voltage across the armature is low at start, and hence this switch remains open. It is so adjusted that it will not close until after switch No. 2 has closed and the motor has speeded up. If the motor is overloaded while running, the relay (R) opens the control circuit of the line switch (No. 1) thus disconnecting the motor from the line. To stop the motor, the "stop" button is pushed. This opens the line switch-control circuit, which causes the line switch to open. Switch No. 1 always opens before No. 3 because the latter is across the armature and receives voltage until the motor has slowed down. Only switch No. 1 is therefore provided with a blow-out coil for breaking the arc when the switch opens. The connections shown in Fig. 96 are for a compound motor with compensating winding. For shunt motors, A_2 and F_2 are connected to the — line.

182. Dynamic Braking. If a motor driving an elevator or other load having considerable inertia is disconnected from the line, the load will drive the motor. Under these conditions a shunt motor will become a generator without any change in the connections. A resistance connected across the armature will absorb power from the load and slow down the machine. The same effect can be produced with series motors if the field winding is connected temporarily to the line (through a suitable resistance). This action is used either to make a quick stop or to retard a descending load. Dynamic braking **for making a quick stop** is employed for elevators, printing presses and machine tools. The controller is arranged to connect a resistance to the armature circuit after it is disconnected from the line. The field circuit is kept connected to the line to give a high braking effect. As the motor slows down, the voltage generated by the armature decreases, and hence the current through the resistance would decrease. To obtain the greatest braking effect, therefore, provision must be made to reduce the resistance as the machine slows down. The final stop is made by a friction brake which is controlled by an electro-magnet. Dynamic braking **for retarding a descending load** is employed on cranes and ore-handling machinery. The motors are generally series wound, so the field winding is placed across the line in series with a suitable resistance. The resistance across the armature is then adjusted until the required speed is secured. Sometimes the armature is connected to the line in series with

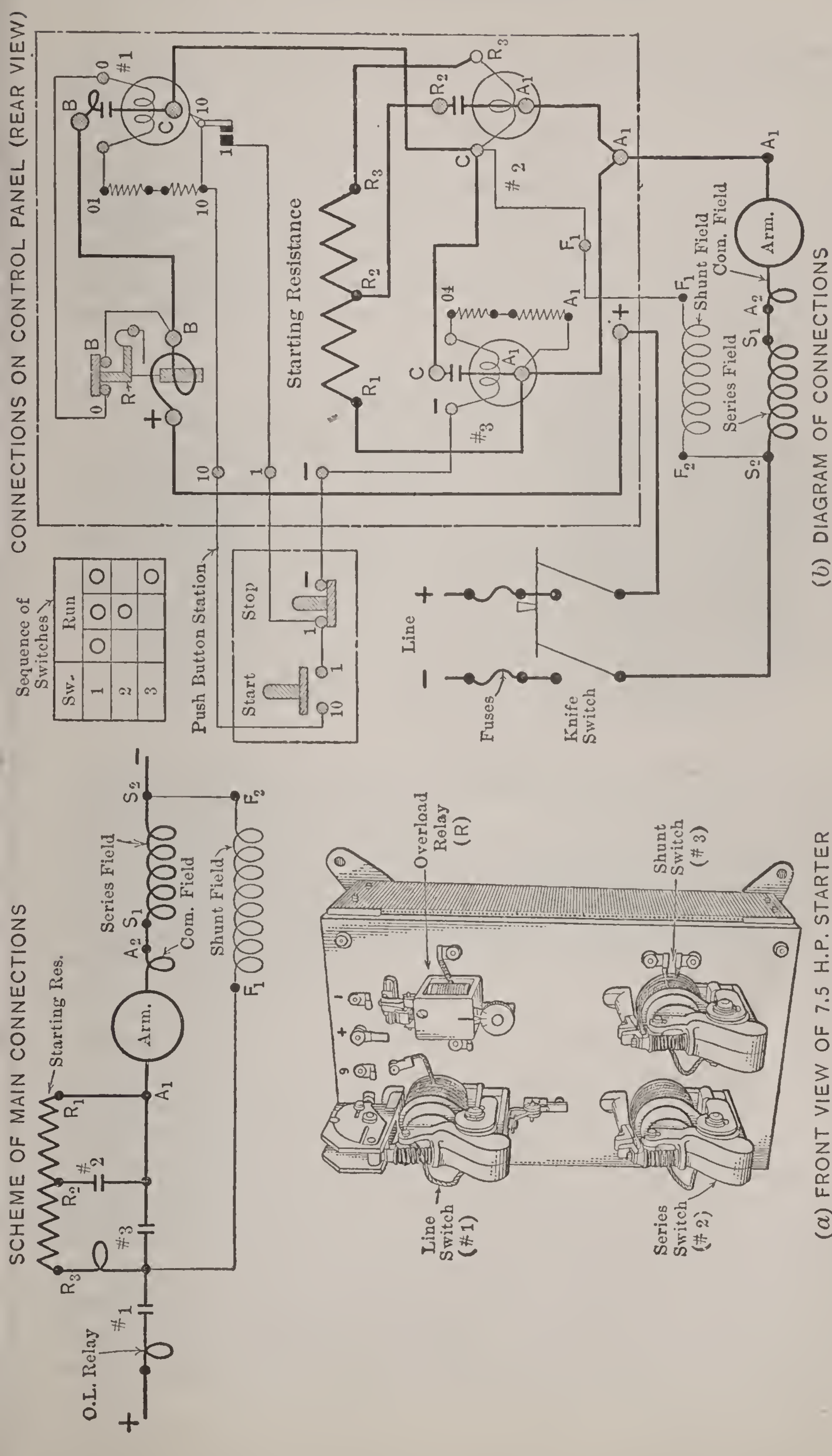


Fig. 96.—Automatic Starter—Magnet Switch Type. Used for control of machine tool drives. (Westinghouse Electric & Mfg. Co.)

a resistance. In this case, the machine will return power to the supply.

A.C. Starting Devices

183. Auto-starters or Compensators are used for squirrel-cage induction motors. They consist of special single-coil transformers (**auto-transformers**) provided with a two-throw switch by which the motor can first be put on a reduced voltage and then thrown on to full voltage. At the same time, the auto-

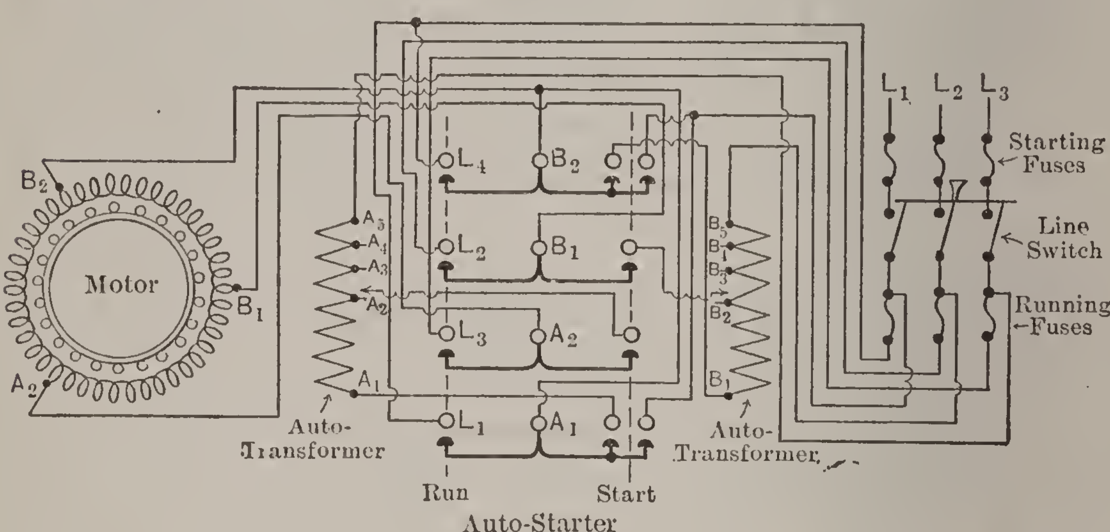


FIG. 97.—Connections for Three-phase Motor with Auto-starter.

To start the motor, contacts on "start" side are closed. After the motor has reached the proper speed, the starter is thrown to "run" position, which opens "start" contacts and closes "run" contacts. This cuts out the auto-transformers and feeds the motor through the running fuses. See Fig. 79 for simplified diagram. Starting voltage can be adjusted by changing connections at taps A_2, B_2; A_3, B_3, etc. The starting fuses are usually located at the point where the branch is connected to the mains. Motor can be reversed by interchanging any two leads at motor. Low-voltage release and overload relays not shown.

transformers are disconnected from the line. The switch for producing these changes has its contacts immersed in oil to reduce the arcing. The principle of operation is illustrated in Fig. 79 and the actual connections for one make of starter are shown in Figs. 97 and 98. Starters for small motors (up to about 20 hp.) have taps giving 50, 65, or 80 per cent of normal voltage at starting. In order to keep the starting current down to a minimum, it is important to select the lowest voltage tap which will start the load. When connected to the 65 per cent tap, most squirrel-cage motors will give nearly full-load torque. Auto-starters are generally provided with a **low-voltage release**

which consists of a magnet connected across the line terminals. This magnet, when the voltage fails, trips a catch which holds the starting lever in the running position. The lever is then returned to the off position by means of a spring. Sometimes an **overload release** is also provided. This consists of two magnets connected in the motor circuit and arranged to open the low-voltage release circuit when a heavy current flows. Usually, however, the overload release is not used, fuses being employed to protect the motor. By reference to Figs. 97

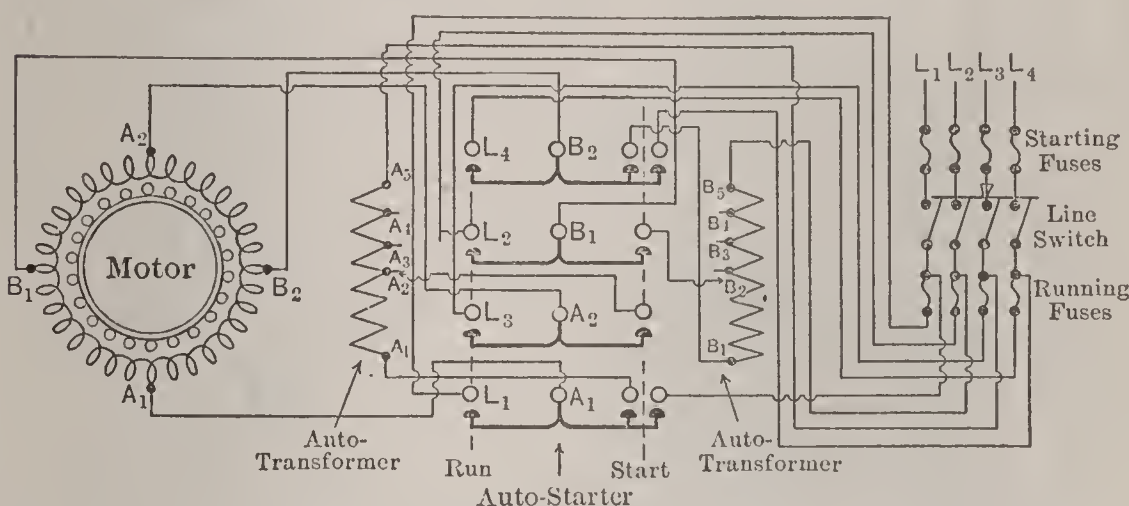


FIG. 98.—Connections for a Two-phase Motor with Auto-starter.

To start the motor, contacts on "start" side are closed. After the motor has reached the proper speed, starter is thrown to the "run" position, which opens "start" contacts and closes "run" contacts. This cuts out auto-transformers and feeds motor through running fuses. Starting voltage can be adjusted by changing connections at taps A_2, B_2; A_3, B_3, etc. The starting fuses are usually located at the point where branch is connected to the mains. Motor can be reversed by interchanging either A_1 and A_2 or B_1 and B_2. For a two-phase, three-wire line, use connections for three-phase starter, connecting L_1 and L_4 to the common wire. Motor can be connected with four leads as in diagram above or with three leads. In the latter case, motor leads A_1 and B_2 are connected together to starter leads A_1 and B_2. To reverse motor, interchange leads A_2 and B_1 at the motor. Low-voltage release and overload relays not shown.

and 98 it will be seen that the running fuses are not in circuit when the lever is in the starting position. If the fuses had to carry the starting current (which is usually for four or five times full-load current) they would not protect the motor when running. The fuses are therefore chosen to allow only a safe overload. This leaves the motor unprotected when starting, except for the fuses which protect the branch wiring.* Auto-starters are not used with slip-ring motors.

*See paragraph 331.

184. Resistance Starters. Two-phase and three-phase **squirrel-cage motors** may be started by means of resistance in series with the motor. The arrangement is shown in Fig. 99. When a resistance starter is used, the motor takes more current from the line than when an auto-starter is used. This can best be explained by an example. A squirrel-cage induction motor

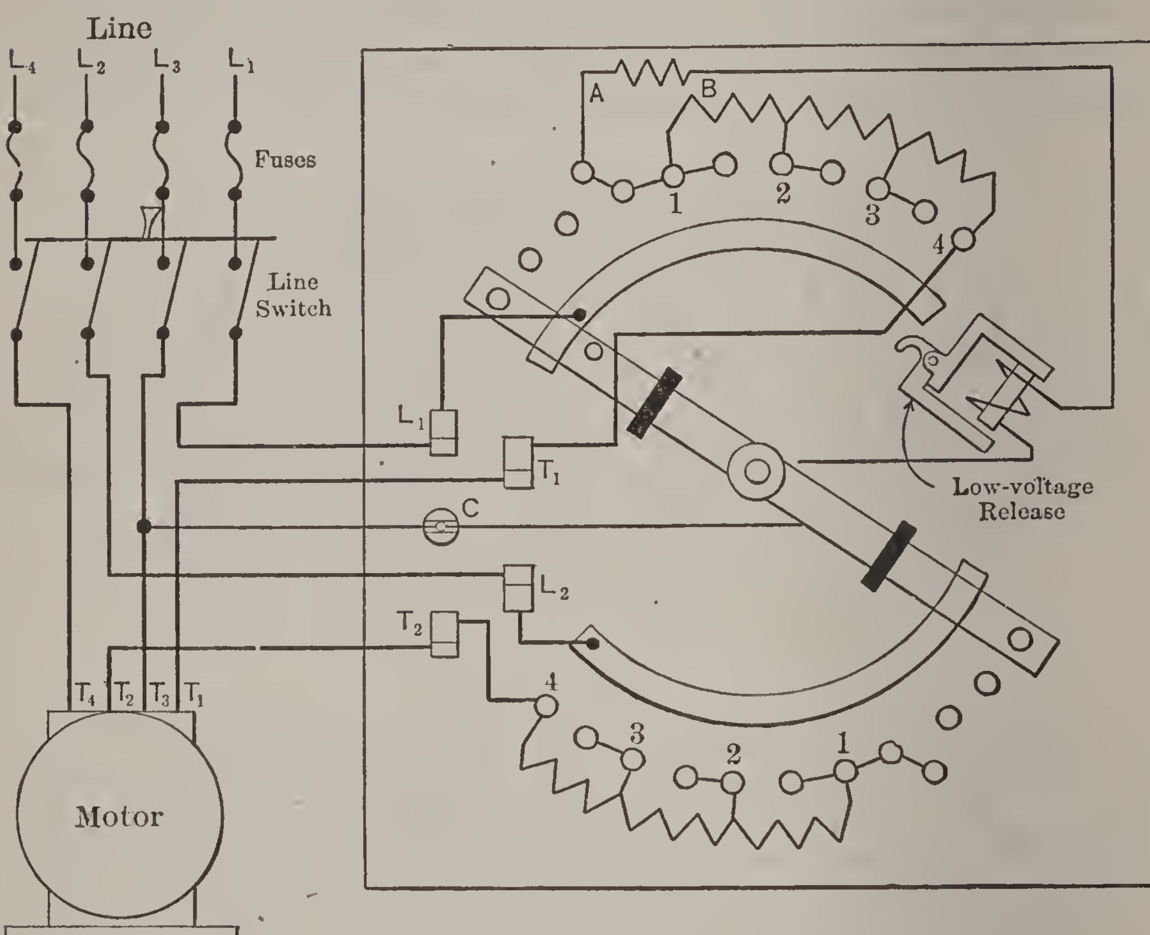


FIG. 99.—Connections of a Resistance Starter for Squirrel Cage Induction Motors.

Connections as shown are for a two-phase, four-wire system. For a two-phase, three-wire system, omit L_4 and use L_3 as common lead. For three-phase, omit L_4.

requires about 65 per cent of normal voltage to start full load and takes about 4.5 times full-load current *in the motor*. Thus a 25 hp., 220-volt, three-phase motor takes 62.6 amperes at full load. (Table 22.) Hence at starting, the *motor* would take $62.6 \times 4.5 = 281$ amperes. The voltage applied to the motor should be $220 \times 0.65 = 143$ volts. If a resistance is used, it must be large enough to carry 281 amperes and must consume the difference between 143 volts and 220 volts. The current

taken from the *line* would be 281 amperes. If an auto-starter is used, the required voltage (143 volts) would be obtained by connecting the motor to proper taps on the transformers. When this is done, *the current in the motor is 281 amperes as before, but the current taken from the line is only* $\frac{143}{220}\times 281 = 183$ amperes. This results from the transformer action and hence gives a decided advantage in favor of the auto-starter. If the load is small enough to allow a lower voltage to be used in starting, a still greater advantage results. The resistance starter also wastes more power than the auto-starter. Because of these facts, the resistance starter is seldom used for squirrel-cage motors, but is employed more frequently for the single-phase commutator type. The principal advantages of the resistance starters are their low cost and their simplicity. These starters are usually provided with a low-voltage release attachment which is connected across the line. Resistance starters are commonly used for **slip-ring induction motors**. With these motors, the stator is connected directly to the line, through a suitable fuse and switch. The resistances are connected in the rotor circuit. The arrangement of connections is shown in Fig. 80 and a view of a starter of this type is shown in Fig. 100. At starting the resistance is all in circuit, and as the motor speeds up the resistance is cut out in steps until finally the slip-rings are short-circuited, and the motor operates practi-

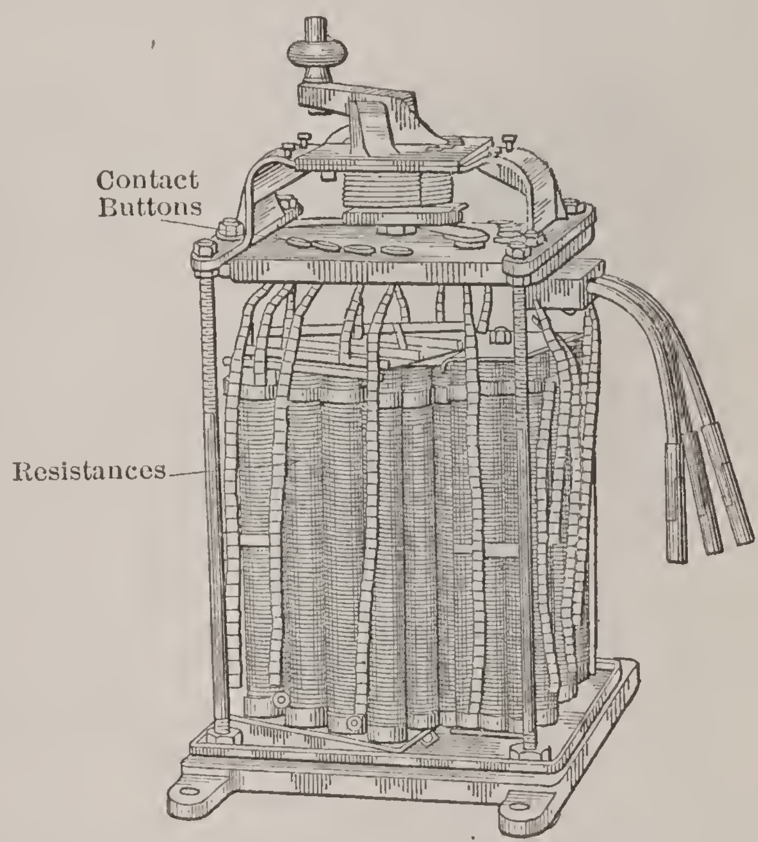


FIG. 100.—Resistance Starter for Slip-ring Induction Motor.

cally like a squirrel-cage motor. If the starting resistance is made large enough, it can be left in circuit and the speed of the motor adjusted by changing the resistance.

185. Star-delta Starting. The necessary reduced voltage for starting a squirrel-cage induction motor can be produced in effect by rearranging the motor windings. Thus, in a three-phase motor, the three groups of coils may be arranged in star (or Y) as shown in Fig. 101*a*. Each winding then receives

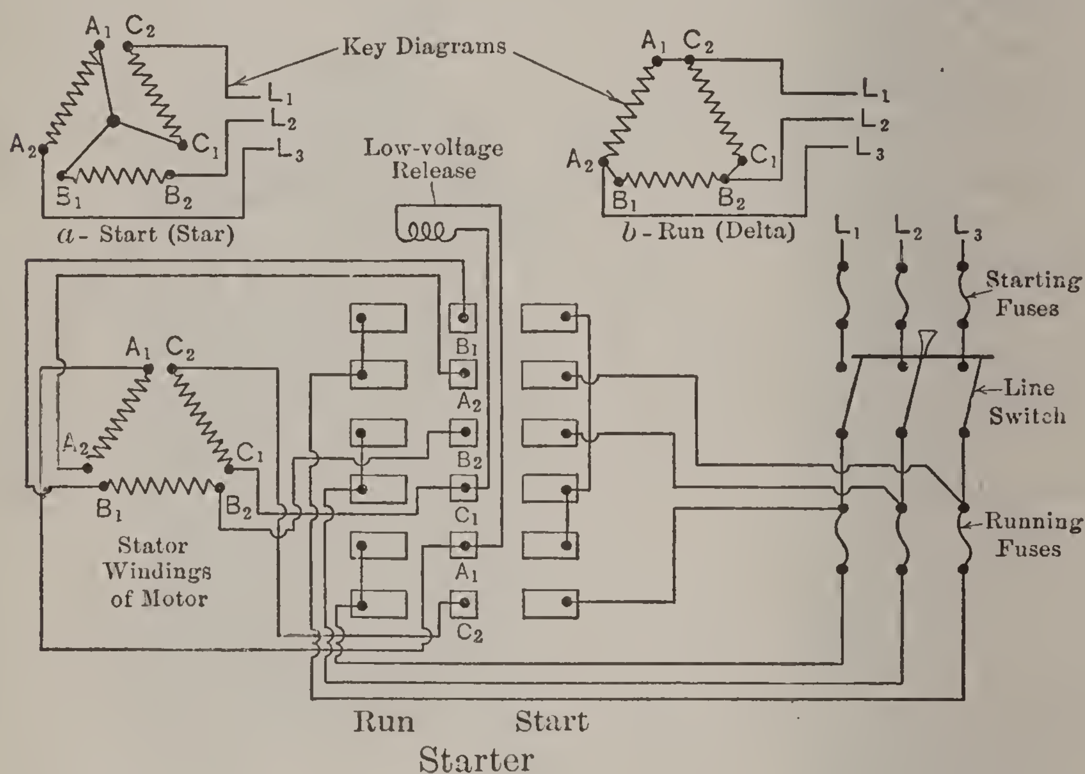


FIG. 101.—Diagram of Star-delta Method of Starting Squirrel-cage Induction Motors.

When switch is in "start" position, center contacts connect with corresponding contacts at right, marked start. After the motor has speeded up, center contacts are thrown to left to "run" position, where they are held by the low-voltage release coil.

0.58 of the line voltage, or in this case $220 \times 0.58 = 127$ volts. After the motor has started, the windings are thrown directly across the line by means of a switch. (Fig. 101*b*.) The voltage across each winding is thereby raised to 220 volts. If the load is not too great, this method is satisfactory, but the starting voltage cannot be adjusted, so that for heavy loads the motor would not receive enough voltage to start. This arrangement is limited in its application to small sizes of motors, where the starting loads are not heavy. The switch used with this

method of starting is usually provided with a low-voltage release attachment, similar to that used with auto-starters.

186. Starting Switches and Fuses. Since squirrel-cage induction motors require large starting currents, some provision must be made to cut out the fuses when the motor is starting, otherwise they would be blown. For small motors which do not require starters, a two-throw switch is used. When the switch is thrown in the starting position the motor is connected to the line without fuses. After the motor has started, the switch is thrown into the running position, which puts the fuses in series with the motor. These fuses are made of proper capacity to give protection against overloads. In order to prevent the switch being left in the starting position, thus leaving the motor unprotected, springs are provided to open the switch if the handle is released while in the starting position. Fig. 78 shows this arrangement. While the switch does not have fuses in the starting position, the motor is protected to some extent by the fuses protecting the branch motor circuit, which must be fused for the starting current.

CHAPTER 11

SELECTING MOTORS FOR INDUSTRIAL PURPOSES

187. Methods of Driving Machines. When machines are driven electrically, either group or individual drive may be used. **Group drive** is a modified form of mechanical drive. The

FIG. 102.—Individual Drive.

Showing entirely enclosed motors belted to small circular saws. Controllers are automatic and are entirely enclosed. Motor is started by closing the switch.

main shafting and belts are eliminated and machines of a similar kind, arranged in groups, are belted to short lengths of comparatively light shafting. Each group is then driven by a motor. By this means the friction losses of the shafting are greatly reduced. With **individual drive** (Fig. 102), each machine is fitted with one or more motors, thus making

it an independent unit. The **advantages** of the individual drive are: (*a*) Increased production, because slipping of belts is eliminated, and speed may always be adjusted to the best value for the work. There is also a greater overload capacity. Since the labor cost of production is a very large item (often 50 per cent or more of the total), this advantage is very important. Experience with the electric drive has shown increases of from 10 to 20 per cent in the output of a plant. (*b*) The location of the tool is independent of the line shaft and an arrange-

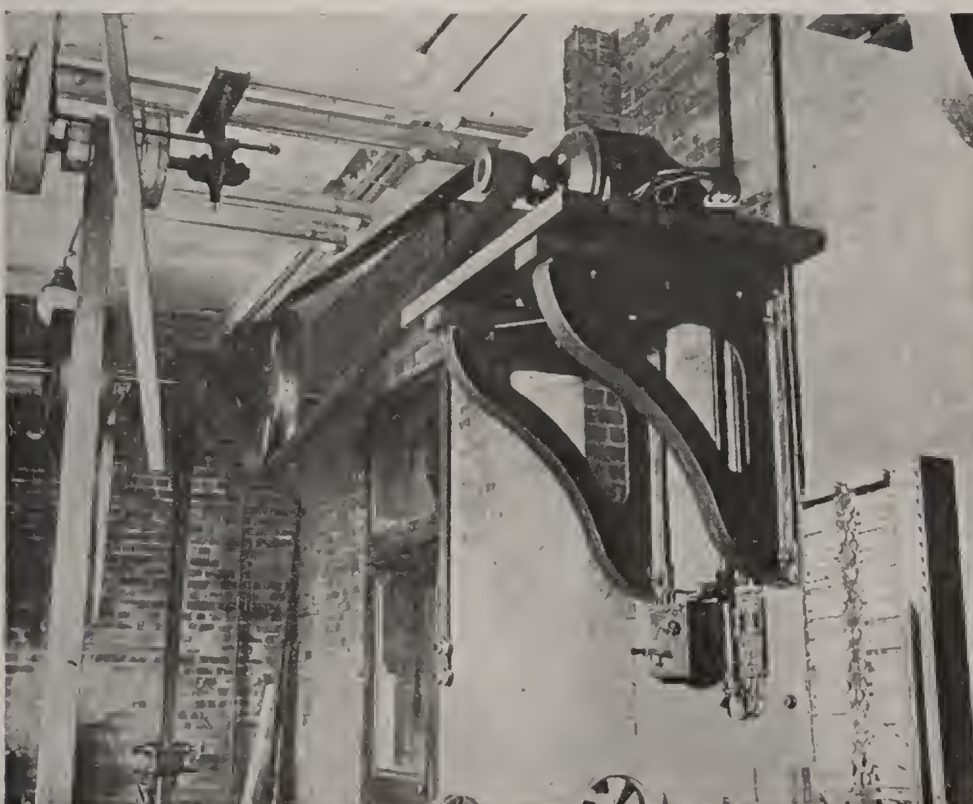


FIG. 103.—Arrangement of Motor for a Group Drive.

ment can therefore be used which will facilitate rapid production with a proper routing of the work through the shop. (*c*) New tools can be added and tools easily rearranged. (*d*) Line shafts, with their troublesome belts, are eliminated. This means greater safety to workmen, a cleaner and better lighted workroom, headroom for overhead cranes, and in some cases a considerably cheaper building, because less headroom and a lighter construction can be used. (*e*) The power losses in transmission are less than with shafting. The total loss, including generator, feeders and motors, is from 20 to 30 per

cent. The first cost of individual drive is, however, greater (about 20 per cent) than group drive. **Group drive** (Fig. 103) is particularly adapted for light machine work, where the individual machines are small and little or no speed adjustment is required.

188. Choosing Type of Motor. The choice as to the use of a.c. or d.c. motors is dependent upon a number of factors besides the kind of machine to be driven. This subject is covered in paragraphs 162 and 220. The choice as to the type of motor, either alternating or direct current, must be based primarily upon the starting and running requirements and upon the character of the surroundings, as regards dust, inflammable material, moisture, etc. Considering load requirements only, the classification given below will apply:

Classification of Motors with Reference to Performance

Local Requirements.	Suitable Type of Motor.	
	A.C.	D.C.
(1) Approximate constant speed, no load to full load.	Induction motor.	Shunt motor.
(2) Semi-constant speed, no load to full load.	Induction motor with high rotor resistance.	Compound motor.
(3) Speed adjustable, but remaining approximately constant from no load to full load for one adjustment.	Nothing available except in special cases for large motors.	Shunt motor with field rheostat.
(4) Speed adjustable, and semi-constant from no load to full load, for one adjustment.	Nothing available except for large motors.	Compound motor with shunt field rheostat.
(5) Varying speed, decreasing greatly with increase of load.	Induction motor with adjustable rotor resistance.	Series motor.

Detailed classifications of the various types of motors are given in paragraphs 150 and 160. With a knowledge of the load requirements, the motor which will be best suited to meet these

requirements can be selected. Open-type motors should be used wherever the operating conditions will permit, because they are cheaper than enclosed motors of the same horsepower rating.* Sometimes dust-proof bearings are required; in other cases entirely enclosed motors are necessary where there is excessive dust. Semi-enclosed motors should not be placed in inaccessible places, as the screens will soon become filled with dirt, making the motor practically an enclosed motor, and consequently increasing the heating. Induction motors will withstand more severe conditions than d.c. motors because of the absence of a commutator, and rarely need to be entirely enclosed to protect them from dust. For the same reason, induction motors do not need as much protection against moisture and there is, of course, no danger of setting fire to inflammable dust.

189. Desirable Speeds for Motors. In general, the motor speed should be as high as conditions will permit. A high-speed motor costs and weighs less than a slow-speed motor and occupies less space. This is shown by the following tabulation:

EFFECT OF SPEED UPON COST AND WEIGHT OF A MOTOR

Shunt wound, 230 volts.

5 Horsepower.			10 Horsepower.			50 Horsepower.		
Speed, R.P.M.	Cost, Dollars.	Weight, Pounds.	Speed, R.P.M.	Cost, Dollars.	Weight, Pounds.	Speed, R.P.M.	Cost, Dollars.	Weight, Pounds.
1800	143	265	1700	231	440	1700	671	1210
1100	173	350	1300	242	510	1100	704	1585
850	240	440	1150	253	545	975	737	1895
			850	286	645	565	990	2700
			730	308	715			

On the other hand, a high-speed motor may be more noisy. With a.c. motors only a limited number of speeds are available, the highest being approximately 1800 r.p.m. for 60 cycles and 1500 r.p.m. for 25 cycles.† In any case, a standard speed should be selected if possible. Table 25 gives the standard speeds commonly used. Unless the motor is directly connected

* See paragraph 166. † See paragraph 164.

to the machine, there is some freedom of choice. Where belts are used, a pulley ratio of more than 6 to 1 is undesirable. A ratio of machine and motor speeds greater than this would require counter shafts or idler pulleys to increase the arc of contact on the motor pulley. These should be avoided where possible.

190. Effect of Low Efficiency. If the motors operate at low efficiency, the cost of power may be considerably increased. The low efficiency may result either because the motors are not fully loaded or because they are poorly designed. It is not always true, however, that the most efficient motor is the best to use. A low-efficiency motor would cost less and take up less space and the saving in cost may sometimes be invested in the business where it will give a greater return. The saving in power by the use of a more efficient motor depends upon the length of time the motor is used each day and upon the cost of power. The high-efficiency motor shows the greatest saving when the cost of power is high and the period of operation long.

191. Relation between Load and Motor Rating. Both the average and maximum conditions of load must be considered when selecting a motor. Sometimes the maximum load requirements occur at starting; in other cases, they may represent an occasional overload of short duration. It is obvious that the motor should be as small as will properly meet the requirements, in order to reduce the first cost to a minimum. This should not, however, lead one to underestimate the load requirements. A motor which is too small would be subjected to frequent overloads, would operate at an excessive temperature and in the case of a d.c. machine there would probably be difficulty in keeping the commutator in good condition. As a result, the cost of maintenance and repairs would be excessive. If the motor is larger than necessary, besides costing more, the operating efficiency would be lower and in the case of induction motors the power factor would be poor. Motors are so designed that they have a good efficiency between one-half and full load. Below half load the efficiency falls rapidly. As a general rule, the size should be so chosen that the motor will operate between three-quarters and full load most of the time. Heavy loads of comparatively short duration can be taken care of by the overload capacity of the motor.* Manu-

* See paragraph 165.

facturers' standard sizes and speeds should be chosen, because they cost less and repair parts can be more easily secured.

192. Determining Amount of Load. The amount of power required for a given machine can be obtained from the manufacturer or, by testing with a temporary motor, or in some cases by calculation. While occasionally the manufacturers are inclined to recommend motors which are too large, the more progressive firms have accurate data on the subject and are able to make proper recommendations provided the work the machine is to be used for is definitely known. The methods of calculation given in the following paragraphs will serve as an approximate guide to the size of motor required. Wherever possible, however, data based on tests should be used. There are a number of tables published which give this information.*

Requirements of Machines

In selecting a motor, both the starting and running requirements of the machine must be considered. The tabulations in paragraphs 150, 160 and 162 will assist in choosing the proper type of motor when these requirements are known. Below are given certain special requirements which have a bearing on the selection.

193. Machine Tools. Group drive is generally preferable for bench and speed lathes and moderate size engine lathes. Heavy lathes are usually driven from individual motors. Other machines which are generally group driven include automatic screw machines, sensitive drills, vertical and radial drilling machines, boring machines, grinders, shapers, slotters and milling machines. Individual drive would be used only for very large sizes of these machines or where they are isolated from the other tools. Large planers are best driven by individual motors. Where individual drive is used for lathes, drills, etc., the shunt-wound motor is best, because wide speed adjustment can be secured by a field rheostat. If induction motors are used they would be of the squirrel-cage type and the speed adjustment would be made by cone pulleys or by a set of gears contained in a "gear box." For driving large planers, a motor which reverses with each stroke of the table is now

* See Standard Handbook for Electrical Engineers and Proceedings of the American Society of Mechanical Engineers.

being used extensively. The motor is compound wound and specially designed for this service. The controller is arranged to permit independent adjustment of the speed of the cutting and return strokes over a wide range. Motors for machine tools are usually rated on a two-hour basis, since there are frequent periods of shut-down or light-load operation. The motor would in general be selected to take care of the average load, since the overload capacity of the motor is sufficient for the maximum load unless it is of long duration. In every case, care must be taken that the motor selected is large enough to properly start the machine under the most severe conditions. The sizes of motors on machines used by piece workers would in general have to be larger than on those where day labor is used. The horsepower required for machine tools can be approximately determined by the following formulas:

Lathes, planers, etc.

$$\text{Hp.} = \text{cubic inches removed} \times K. \quad . \quad . \quad . \quad (1)$$

The cubic inches of metal removed are found by multiplying together the depth of cut and the feed, expressed in fractions of an inch per revolution or stroke and multiplying by twelve times the cutting speed in feet per minute. For a lathe, if the speed, in revolutions per minute, is known the cutting speed can be found by multiplying the diameter of the work in inches by the revolutions per minute and dividing the result by 3.82. The value of K is given by the tabulation below:

Metal.	K.* Horsepower per Cubic Inch of Metal per Minute.
Cast iron	0.3–0.5
Wrought iron	0.6
Machinery steel	0.6
Steel (0.50% carbon)	1–1.25
Brass and similar alloys	0.2–0.3

* Am. Soc. Mech. Engr's, Vol. 32, p. 199.

Example 1. Cutting speed 60 ft. per minute, $\frac{1}{16}$-in. feed, $\frac{1}{4}$-in. depth of cut.

$$\text{Cubic inches per minute} = \tfrac{1}{16} \times \tfrac{1}{4} \times 60 \times 12 = 11.$$

For machinery steel:

$$\text{Hp.} = 11 \times 0.6 = 6.6 \text{ Hp.}$$

Drills. The cubic inches of metal removed per minute are found by the formula:

$$\text{Cubic inches} = 0.7854 \times d^2 f. \quad \ldots \quad (2)$$

Where d = diameter of drill in inches;
f = feed in inches per minute.

The values of K for drills are about double those given above.

Example 2. For a 2-in. drill working in cast iron, with a feed of 1.5 in. per minute, we would have:

$$\begin{aligned}\text{Cu.in.} &= 0.7854 \times 2^2 \times 1.5 \\ &= 4.7 \text{ cu.in. per min.}\end{aligned}$$

From equation (1)

$$\begin{aligned}\text{Hp.} &= 4.7 \times 0.5 \times 2 \\ &= 4.7 \text{ hp.}\end{aligned}$$

The values of K given do not include the friction of the machine. Usually this is not more than 3 per cent of the load, so it can be neglected in determining the size of motor required. For small tools, such as sensitive drills, the friction load is a large proportion of the total load. Wherever possible it is best to determine the horsepower required by means of a test. In the absence of this, published data,* or information from the manufacturers can be used.

194. Wood-working Machinery. For most wood-working machinery, the starting load is light and the machine must operate at a constant speed. The ordinary types of induction motors are therefore well adapted to this service and are generally used. They are more satisfactory than d.c. motors because of the absence of a commutator and their large overload capacity. For most machines, standard squirrel-cage motors are satisfactory. Large circular saws and band saws for sawing logs, large planers and matchers require a large starting torque and are subject to heavy fluctuations in load. For this service slip-ring motors with resistance placed permanently in the circuit, or squirrel-cage motors with a large slip, are used.

* An excellent list of this kind is given in a publication of the Westinghouse Electric and Mfg. Co. entitled "Electric Motors for Machine Tools."

195. Pumps. The service which a motor has to perform depends first upon the kind of pump used. **Reciprocating or plunger pumps** require a heavy starting torque unless the pressure on the pump is relieved with a by-pass. Only small pumps are, accordingly, started under pressure. Usually a squirrel-cage induction motor or a shunt motor is employed. Where it is desired to change the quantity of liquid discharged by the pump, the speed is varied, by means of a field rheostat, in the case of d.c. motors, and by the use of a slip-ring motor where alternating current is used. **Centrifugal pumps** have to be treated somewhat differently because of their peculiar action under different heads. With a reciprocating pump operating at constant speed, an increase in the resistance against which the pump is working increases the pressure, since the volume discharged keeps nearly the same. Hence the load on the motor increases. With a centrifugal pump, on the other hand, an increase in the resistance reduces the load. If the head is reduced on a reciprocating pump, the power required is less; with a centrifugal pump, however, a reduction of head increases the volume of water delivered and the load increases. Some centrifugal pumps are so designed that the increase in load at the minimum head is only about 25 per cent, and this can be taken care of by the overload capacity of the motor. In others, however, the load is considerably greater than this, so this point must be investigated carefully when selecting a motor. If the speed of a centrifugal pump is reduced below normal, the

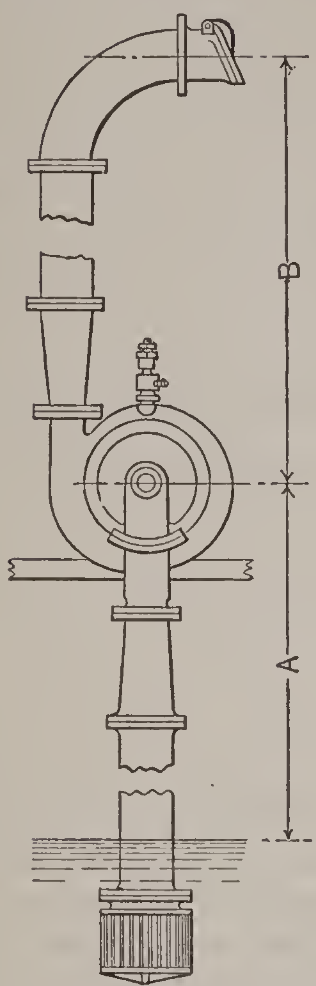


FIG. 104.—Diagram Showing Head on a Centrifugal Pump.

A = *suction lift*, or the vertical distance in feet between centre of pump and level of water at supply.

B = *discharge head*, or the vertical distance in feet from centre of pump to centre of discharge outlet.

Friction head is the head in feet, corresponding to friction in both suction and discharge pipes. If these pipes are long, the friction head cannot be neglected. With long-radius elbows, each quarter turn adds about 1 foot to the head.

Total head = suction lift + discharge head + friction head.

quantity of water discharged is reduced. Even the slightly lower speed of a shunt motor when first started (with windings cold) is sufficient to affect the output considerably. For this reason a field rheostat frequently is provided so that the speed can be maintained normal at all times. The starting characteristics of centrifugal pumps should also be considered. In starting, the discharge valve is usually entirely closed to make the starting load as light as possible. Under these conditions, the torque is from 15 to 25 per cent of full-load torque and drops slightly as soon as the pump turns over. The pump casing is filled with water, which is churned round when the motor is up to speed, and this produces about half load on the pump even with the valve closed. Shunt motors, or either squirrel-cage or slip-ring induction motors, are suitable for driving pumps. Reciprocating pumps are generally geared or belted to the motor, while centrifugal pumps, because of their high speeds, can generally be direct connected to advantage. The horsepower of a pump can be calculated from the formula

$$\text{Hp.} = \frac{\text{Total head} \times \text{gallons per minute}}{3950 \times \text{efficiency of pump}}.$$

The total head includes the suction lift, discharge head, and friction head. An explanation of these quantities is given in Fig. 104. For reciprocating pumps the efficiency is from 50 to 80 per cent depending upon the size and working condition of the pump. For centrifugal pumps, the efficiency is from 50 to 70 per cent.

Example. Determine the horsepower required to drive a centrifugal pump delivering 100 gals. per minute, with a suction head of 15 ft. and a discharge head of 50 ft. There is one elbow in the suction pipe and two elbows in the discharge line. The length of the line is short, and hence friction can be neglected. Allow 1 ft. loss for each elbow.

$$\begin{aligned} \text{Total head} &= 15 + 50 + 1 + 1 + 1 \\ &= 68 \text{ ft.}, \end{aligned}$$

$$\begin{aligned} \text{Hp.} &= \frac{68 \times 100}{3950 \times 0.50} \\ &= 3.44 \text{ hp.} \end{aligned}$$

196. Blowers and Fans. **Centrifugal fans** have the inlet at the centre and discharge through an opening near the outside circumference. **Propeller or disk fans** move the air in a direc.

tion parallel to the shaft, similar to the propeller of a ship. **Blowers** include positive-pressure rotary blowers, which create a pressure by direct compression. (For example, the Root blower.) The horsepower of any fan or blower increases greatly with the speed.* The horsepower of a centrifugal fan at constant speed, in general, decreases as the area of the discharge opening is decreased, and with opening entirely closed is only about 20 per cent of the power required with full opening. The horsepower for a propeller fan increases as the area of the discharge opening is decreased, being about double when the opening is entirely closed. With a positive-pressure blower, the horsepower increases very rapidly as the area of the discharge opening is decreased. With centrifugal fans, therefore, the discharge is closed to reduce the load, while with the other two types the discharge is left wide open. For centrifugal fans and pressure blowers, shunt motors are used for d.c. systems. For propeller fans either shunt or series motors can be used, the latter being better. With a.c. systems, standard squirrel-cage motors are generally used. Fans and blowers frequently must be capable of speed adjustment. With d.c. motors, this is accomplished by field or armature rheostats or both, and with induction motors by means of resistance in the rotor circuit. Motors may be direct connected to centrifugal fans and to small propeller fans. For blowers and large-sized fans, however, the speeds are so low that a belt or chain drive is preferable.

197. Compressors. The load on air compressors is generally intermittent. In some cases the machine is started and stopped as the demand for air changes, but generally the compressor is run continuously and an unloading valve is used to reduce the output of the compressor as required. When the compressor is started and stopped, the unloading valve is used to reduce the starting load. The starting conditions are therefore not severe in either case. Flywheels are used to equalize the load.

198. Elevators. These machines require a heavy starting torque and a constant running speed. One of the great problems in high-speed elevator work is to make accurate landings. This is very satisfactorily accomplished with d.c. motors by making them act as generators feeding into a resistance. With a.c. motors the control is not as satisfactory, because a friction brake

* Proportional to the cube of the speed.

must be depended upon to bring the car to rest. The d.c. motors used have a heavy series winding which is employed in starting and is cut out when running, so the machine operates as a shunt motor. Slip-ring induction motors are generally used with a.c. systems. For high-speed service a two-speed slip-ring motor is used. Two separate windings are provided, one high-speed for starting and running and the other low-speed for stopping. By this means, the motor can be made to act as a generator until the elevator has reached one-third or one-fifth normal speed, after which a friction brake must be used to bring the car to rest.

199. Hoists. These require a large starting torque. The running speed may be variable to suit the load. D.c. motors for small hoists are generally series wound, although sometimes compound motors are used. With alternating current, slip-ring motors are employed. For very large hoists, d.c. motors operated from a special motor generator set with a heavy flywheel are used. The horsepower required to hoist a load can be determined from the formula:

$$\text{Hp.} = \frac{\text{Load in pounds} \times \text{speed in feet per minute}}{33{,}000 \times \text{efficiency of hoist}}.$$

The efficiency is from 60 to 80 per cent, the latter figure being for large, well-designed machines.

Example. Required the horsepower necessary to operate a hoist lifting 6000 lbs. at a speed of 30 ft. per minute.

$$\text{Hp.} = \frac{6000 \times 30}{33{,}000 \times 0.60}$$
$$= 9.1 \text{ hp.}$$

200. Cranes. The starting torque of cranes is high and the running speed may vary with the load. With d.c. systems, the series motor is therefore used, since it tends to slow down with heavy loads, and thus relieve the power house of heavy current fluctuations. Compound motors* are also used. With a.c. systems the slip-ring type of induction motor is best. The squirrel-cage type with large slip simplifies the control devices and is used for small installations. It is usually difficult to estimate the power requirements, so that the recommendations of the manufacturer must generally be taken.

* Series-shunt type. See paragraph 148.

201. Steel Mills. Motors for these places must have high overload capacity and great mechanical strength and must frequently operate under very severe conditions as regards dust and dirt. A.c. motors are used almost exclusively for steel mills. For motors driving the main rolls, the slip-ring type is used.

202. Cement Mills. Only induction motors are suitable for cement mills because of the dust. The bearings should be made dust proof. Slip-ring motors are used on ball and tube mills and on crushers which require a large starting torque. They are also used on kilns and dryers when speed adjustment is required. For the other machines, standard squirrel-cage motors are satisfactory. The dust causes rapid deterioration of belts, and therefore direct connection is preferable wherever possible. A flexible coupling should be used to reduce the shocks on the motor.

203. Tanneries. Either the shunt-wound, d.c. motor or the squirrel-cage induction motor has suitable operating characteristics for driving machinery in tanneries. In some parts of the process, however, the operating conditions are very severe owing to the presence of moisture and acid fumes. For this reason induction motors are best adapted for the service and are generally used. The windings are specially treated to withstand the acid fumes. Switches and fuses are enclosed in moisture-proof boxes. Group driving is commonly employed, although individual drive is favored for some of the machines. Group drive is best adapted for staking, rolling and glazing machines, for the tanning and washing drums and for shaving and shanking machines. Individual drive is best for belt-knife splitters, fleshing and unhairing machines, color drums, exhaust fans, pumps, etc.

204. Textile Mills. As a rule, the loads are steady and extremely close speed regulation is required. The starting loads are not severe. There is always more or less lint in the air and therefore the motors have to be specially protected. Squirrel-cage induction motors are generally used. These motors are especially designed to give very close speed regulation and a high efficiency and power factor under working conditions. Because of the lint, all air ducts in the motors are eliminated and the bearings are made dust tight. Enclosed motors are not used generally, but the rotor is made without

any projections to catch the lint. There is a tendency at present to use individual motor drive, particularly for looms and spinning frames. Overhead shafting and belts are objectionable because they are likely to cause damage to the goods from dirt, oil, etc. It is also difficult to maintain constant speed due to slipping of belts.

205. Group drives require constant-speed motors; either shunt-wound d.c. or squirrel-cage induction motors. If the amount of shafting is large, requiring a large-size motor as compared with the generator, the slip-ring type may be used to reduce the starting current. Where a motor is used to drive a large amount of shafting to supply, for example, several floors in a mill, a synchronous motor is sometimes used to give a better power factor. The size of motor required for a group drive is less than the total horsepower used by the machines driven by it, because they do not all require full load at the same time. The approximate size of motor can be determined by adding together the horsepower required for each tool and multiplying this sum by 0.30 or 0.40. To this should be added the friction of the line shaft, which is approximately 1 hp. for 10 to 15 ft. of main shaft. This allows for friction of countershafts and idler pulleys. Where there is one machine much larger than the others, this should be included in the total at its actual horsepower requirements and not reduced to 30 or 40 per cent as above described. Wherever possible, however, the power requirements should be determined by a test with a temporary motor.

206. Selection of Control Equipment.* This is determined to a large extent by the character of work the motor is to perform. As a rule, starters and control switches should be entirely enclosed to protect the workman and keep the working parts in good condition. Where a motor may be subject to frequent overloads as in cranes, hoists, etc., circuit breakers should be used to save the time and expense of replacing blown fuses. For small motors, the circuit breaker may be combined with the starter (overload release). When the motor is started only occasionally the face-plate type is satisfactory. For tools which are started frequently the drum-type controller should be used. The controller should be so located that it is within convenient reach of the workman when he is in position to operate the tool.

* Refer to Chapter 10.

207. Methods of Connecting Motor to Load. The motor may be directly connected to the load or it may be driven through belts, gears, chains, or ropes. **The direct drive** is most satisfactory where the speed of the machine is high enough to give an economical speed for the motor. **Belt drives,** using leather, canvas or rubber belts, are employed where there must be a difference in speed between motor and load, and where the distance between motor and driven shaft is considerable. The belt drive is quiet, and is suitable for transmitting large amounts of power, provided the distance between shafts is sufficient. It has the further advantage of flexibility; thus the shocks to motor or machine are not as severe as with the positive drives. There is, however, a certain amount of slip (from 2 to 4 per cent). **Gear drives** are used where the distance between shafts is too small to allow the use of belts, and where a positive drive is required. The drive is usually more noisy than a belt, but it has the advantage of saving in space because the motor can be placed close to the machine. The loss in power with gears varies from 2 to 10 per cent. **Chain drives** (Fig. 106) are used where the distance between shafts is too short for belts and too long for connection by gears and where a positive drive is required. The pulleys are toothed somewhat like gear wheels, and are connected by a specially designed chain. As in the gear drive, there is no slip, but the chain is somewhat more noisy than a belt. The chain drive can transmit large amounts of power at low speeds and is not seriously affected by moisture, oil, or grease. It has the further advantage that stretching, due to use, does not cause slipping as with belts. **Rope drives** use grooved pulleys and steel or fibre ropes. They are used where power must be transmitted comparatively long distances, for example, between two buildings, and also where the transmission is made at an angle or in a vertical direction. Rope drives cost less than belt drives, but have certain disadvantages, due to the difficulties in equalizing the load carried on the various ropes.

208. Belt Drives. Leather belts are most commonly used and are very satisfactory where they can be kept dry and free from oil. Two thicknesses of leather belts are commonly used: single (about $\frac{1}{4}$ in. thick) and double (about $\frac{3}{8}$ in. thick). Three- and four-ply belts are also used to some extent (for heavy service). Single belts should be used on pulleys less than

12 in. in diameter. The size of belt required to transmit a given horsepower can be found by the aid of Table 27.

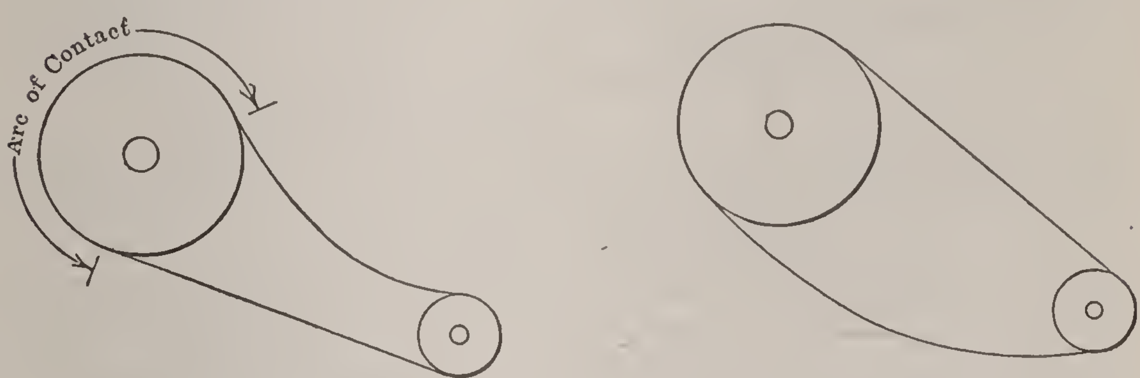
Example 1. Required the width of belt necessary to transmit 10 hp. with pulleys each 6 in. in diameter running at 1400 r.p.m. A single belt would be used. From Table 27, we find that a belt 1 in. wide will transmit 2.44 hp. The width of belt is therefore $10 \div 2.44 = 4.1$ in. A 4-in. belt would therefore be sufficient.

Example 2. Required the width of belt for a drive to transmit 50 hp. with one pulley 24 in. in diameter running at 700 r.p.m. and the other pulley 48 in. in diameter. A double belt would be used in this case. The horsepower for a 1-in. belt would be

$$6.08 + (6.83 - 6.08)0.5 = 6.46 \text{ hp.}$$

Since the pulleys are of unequal diameter (ratio 2 to 1) the horsepower is $0.98 \times 6.46 = 6.32$ hp.

For 50 hp., the width should be $50 \div 6.32 = 7.9$ in.; hence an 8-in. belt would be used.



a. Correct. *b.* Incorrect.

FIG. 105.—Arrangement of Belt Drives.

Rubber belts are made of two or more layers of canvas coated with a rubber composition. These belts are specially adapted for use in damp places or out of doors. They are very easily damaged by oil or grease. **Cotton or canvas belts** are also used to some extent, but for general service they are not as satisfactory as leather. **In calculating a belt drive,** the following rules may be used:

Let S = revolutions per minute of driven shaft;
s = revolutions per minute of driving shaft;
D = diameter in inches of pulley on driven shaft;
d = diameter in inches of pulley on driving shaft.

Then

$$S = \frac{s \times d}{D}. \quad \text{. . . . . (1)} \quad \text{or} \quad s = \frac{S \times D}{d}. \quad \text{. . . . . (2)}$$

$$D = \frac{s \times d}{S}. \quad \text{. . . . . (3)} \quad \text{or} \quad d = \frac{S \times D}{s}. \quad \text{. . . . . (4)}$$

Wherever possible, the belts should be run with the slack side on top (Fig. 105*a*), as this gives a better contact with the smaller pulley. Vertical belts should be avoided as much as possible. The distance between shafts should not be less than the following:*

Approximate Pulley Ratio.	Distance between Shafts, Feet.
2–1	8
3–1	10
4–1	12
5–1	15
6–1[1]	20

[1] This ratio should not be exceeded.

Excessively small pulleys on motors should be avoided because they require a large belt tension, which puts an excessive strain on the motor bearing and may cause overheating. The belt is also more likely to run off the pulley when the machine is being started. Table 26 gives the standard size pulleys recommended by motor manufacturers. Cemented belt joints are better than laced joints, especially for high-speed service.

209. Gear drives have the advantage that there is no slip. The speed ratio can be greater than for belting. High-speed gears (surface speeds above 600 ft. per minute) are noisy but by the use of rawhide or cloth pinions higher speeds (up to 2000 or 3000 ft. per minute) can be used. The speed of shafts driven by gears can be calculated as follows:

Let T = number of teeth in driven gear;
t = number of teeth in driving gear;
S = revolutions per minute of driven gear;
s = revolutions per minute of driving gear.

Then

$$S=\frac{s\times t}{T}. \quad . \quad . \quad . \quad . \quad . \quad (1) \qquad \text{or} \qquad s=\frac{S\times T}{t}. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$T=\frac{s\times t}{S}. \quad . \quad . \quad . \quad . \quad . \quad (3) \qquad \text{or} \qquad t=\frac{S\times T}{s}. \quad . \quad . \quad . \quad . \quad . \quad (4)$$

* American Handbook for Electrical Engineers.

210. Chain drives, like gears, operate at good efficiency when properly designed. They have an advantage over gearing in that the work is distributed over a number of teeth (Fig. 106*a*). Well-designed chains are quieter than gears and have the further advantage that the distance between shafts can be varied to suit requirements (Fig. 106*b*). The speed of a shaft driven by a chain depends upon the number of teeth in the driving and

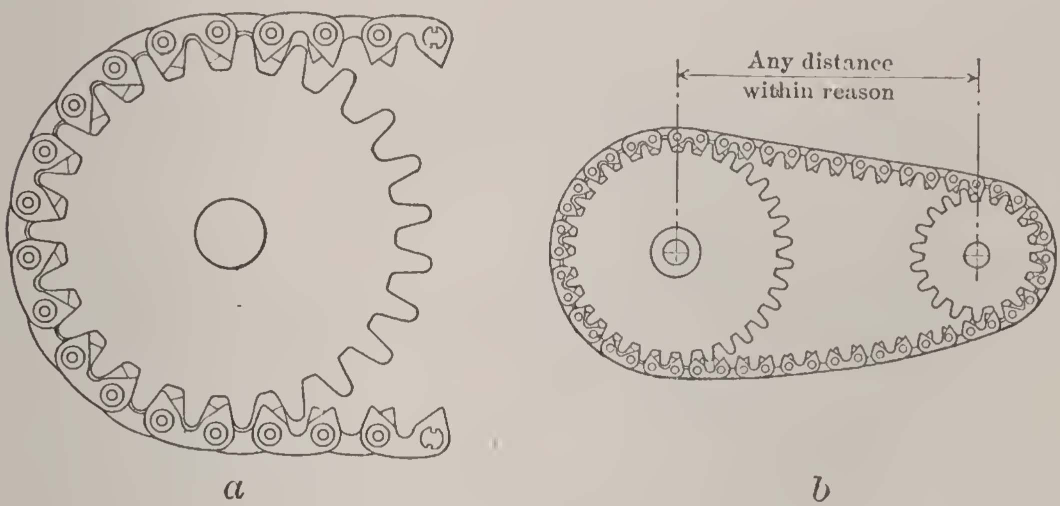


FIG. 106.—Chain Drive.

driven sprockets, and the calculation can be made by the same formulas as for gearing.*

211. Ordering a Motor. The specification should include the following: Kind of motor, voltage, frequency (for alternating current), horsepower, whether for continuous or intermittent service, speed, kind of machine to be driven, whether open or enclosed, details of drive (belt, gear, etc.), whether adjusting rails are to be furnished, type of controller. It is also well to give the manufacturer as much information as possible regarding the service which is to be performed, to enable him to recommend a satisfactory motor. It is particularly important to give information regarding unusual operating conditions such as excessive temperature, dust, dirt, moisture, etc.

* See paragraph 209.

PART III. INTERIOR WIRING

CHAPTER 12

SYSTEMS OF WIRING

212. Methods of Power Supply. There are two methods of distributing electricity for lighting and power supply. The **series system**, sometimes called the constant-current system

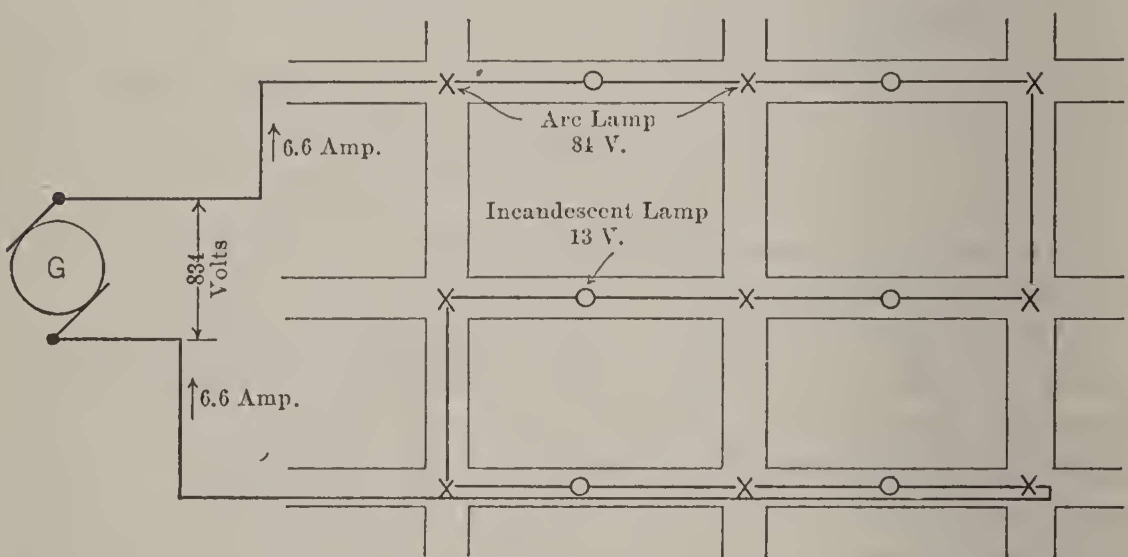


FIG. 107.—Series System of Distribution.

NOTE.—Voltages indicated for lamps include allowance for line drop. Series circuits usually have more lamps in one circuit than are shown in diagram.

as its name indicates, has all the lamps or motors connected in series in one circuit (Fig. 107). The *current* is kept constant regardless of the load, and therefore all lamps or motors must take the same current. The total voltage of the circuit is the sum of the voltages required for each piece of apparatus. The total *voltage* therefore increases as the load is increased by adding lamps. With the **multiple system**, sometimes called the con-

stant-potential system, the *voltage* is maintained practically constant, whereas the *current* increases as load is added. The total current divides between the various lamps or motors which are connected to the system, and hence disconnecting a portion of the load has no effect upon the operation of the load which remains. The simplest method for multiple distribution is the two-wire system shown in Fig. 108. Other systems include three-wire and other multivoltage systems, three-phase and two-phase systems. All of these are classed as multiple systems, since the voltage is maintained nearly constant and the lamps or motors are connected directly across the line. The

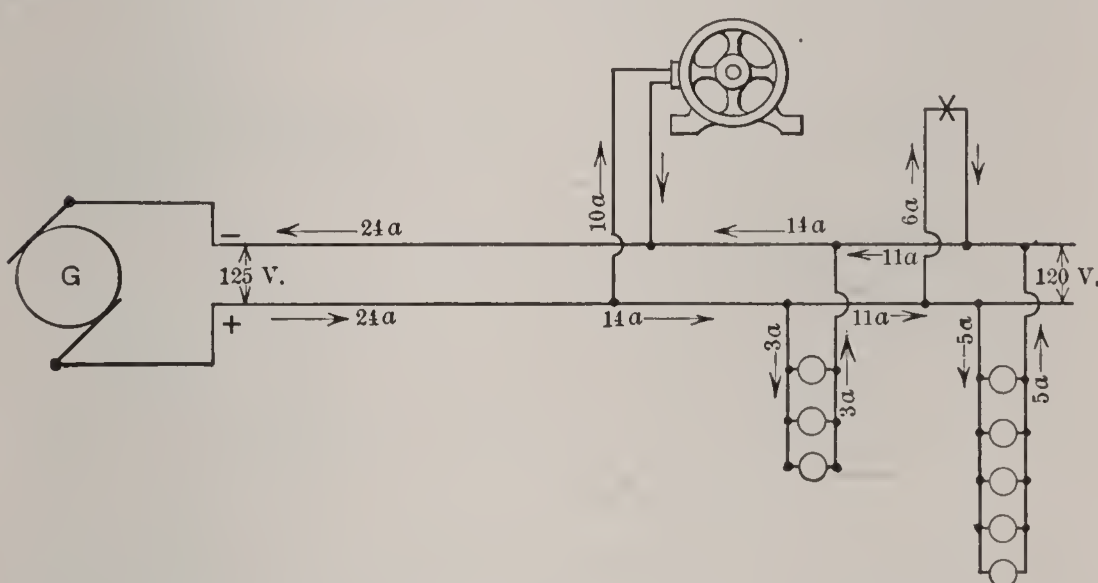


FIG. 108.—Multiple System of Distribution.

series system is especially well adapted for street lighting, because a single wire can be run through each street and the lamps cut into the circuit at any point (Fig. 107). Also, since the current is small (usually 4 to 6.6 amperes), a small size wire may be used. The system operates at a high voltage, however, and consequently requires careful insulation and is a source of danger to anyone who might come in contact with the circuit. It is not possible to carry a large load on a single circuit and it operates efficiently only when fully loaded. For these reasons, it is not well suited for interior lighting and is now very rarely used for that purpose. It is not used for motors at the present time* because of the high voltage and the

* With the exception of a few special European installations.

difficulties in regulating the motors with changes in load. Only the multiple system will be considered in the chapters following.

213. Effect of Voltage upon Cost of Wiring. If a given amount of power is to be transmitted, it is important to use as high a voltage as other conditions will permit. This reduces the current required and thus reduces the size of wire necessary. This is apparent from the following:

EFFECT OF VOLTAGE UPON SIZE OF CONDUCTORS

Based on feeder to transmit 100 kw. a distance of 1000 ft. with 5 per cent line loss (two-wire system)

Voltage.	Amperes.	Line Loss, Volts.	Line Loss, %	Size of Feeder,[1] Cir. Mils.	Percentage of Copper,[1] 120-volt System =100%.
120	833	6	5	2,970,000	100
240	417	12	5	744,000	25
600	167	30	5	119,000	4
1200	83.3	60	5	29,700	1
2400	41.7	120	5	7,440	0.25

[1] In an actual case the feeder would be taken as the nearest standard size, which would change the percentage slightly. Correct for d.c. and nearly correct for a.c. systems.

The percentage voltage loss in the lines is made the same in each case, since it is the *percentage* loss and not the *actual* loss which fixes the limit in each case. In other words, the operation of lamps or motors would be as satisfactory on either a 120- or a 240-volt system as long as the percentage drop is the same. The *actual voltage drop* in the example given would be 6 volts for the 120-volt system and 12 volts for the 240-volt system. It is apparent that, if the power transmitted is kept the same, the current required for the 240-volt system is one-half that for 120 volts. Since the allowable drop is doubled (the *same* percentage) the copper required is only *one-quarter* that needed for the 120-volt system. This means that the size of feeders for *equal percentage loss* varies inversely as the *square* of the voltage. This statement is correct for d.c. cir-

cuits and is nearly correct for a.c. circuits. The tabulation above takes into account voltage loss only. Other factors enter into this question, such as the greater cost of the high-voltage apparatus, the danger to users of the power, more expensive maintenance, etc., so that the voltage used must frequently be a compromise.*

214. The Two-wire System. The arrangement of lamps or motors is shown in Fig. 109.† This system may be used for supplying either direct or alternating current and when used for the latter is generally called a **single-phase system.** The two-wire system is very simple, but with direct current only one voltage can be supplied. This is a disadvantage when

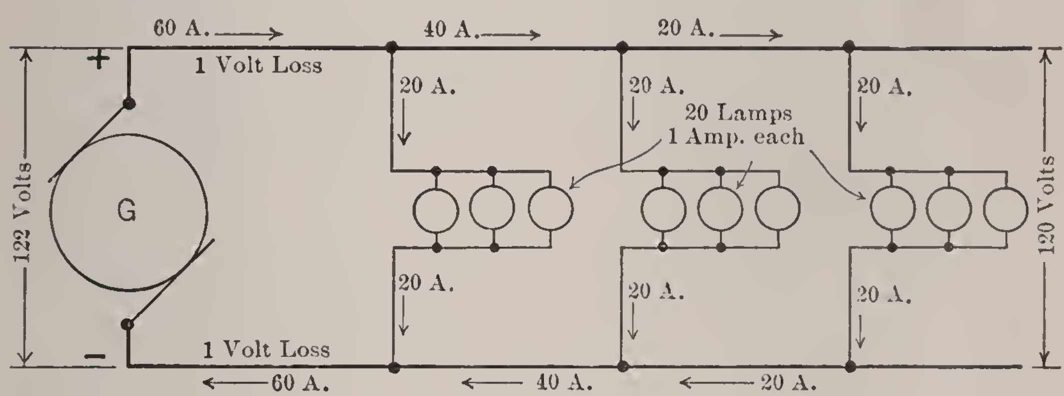


FIG. 109.—Two-wire System.

operating both lamps and motors. Lamp voltages are limited to 240 volts, while for motor circuits a higher voltage is frequently desirable. With single-phase systems, the voltage can be changed by means of transformers, but single-phase motors are not satisfactory except in small sizes.

215. The Three-wire System. In order to use a high voltage for transmitting the energy and at the same time to employ low-voltage lamps or other devices, a series arrangement as illustrated in Fig. 110*a* might be used, provided the two lamps in a branch circuit each require the same current. If lamp (1) is extinguished or burns out, lamp (2) is also extinguished. If the junctions between the lamps are connected together

* See paragraph 220.

† In this figure and those illustrating the other systems, the field connections, switches, circuit breakers, etc., are omitted, as they do not enter into the discussion and would only complicate the diagrams. See Table 47 in Appendix A for explanations of symbols used.

(line B, Fig. 110*b*) a circuit is still maintained through lamp (2) even when (1) is extinguished. This condition is shown in

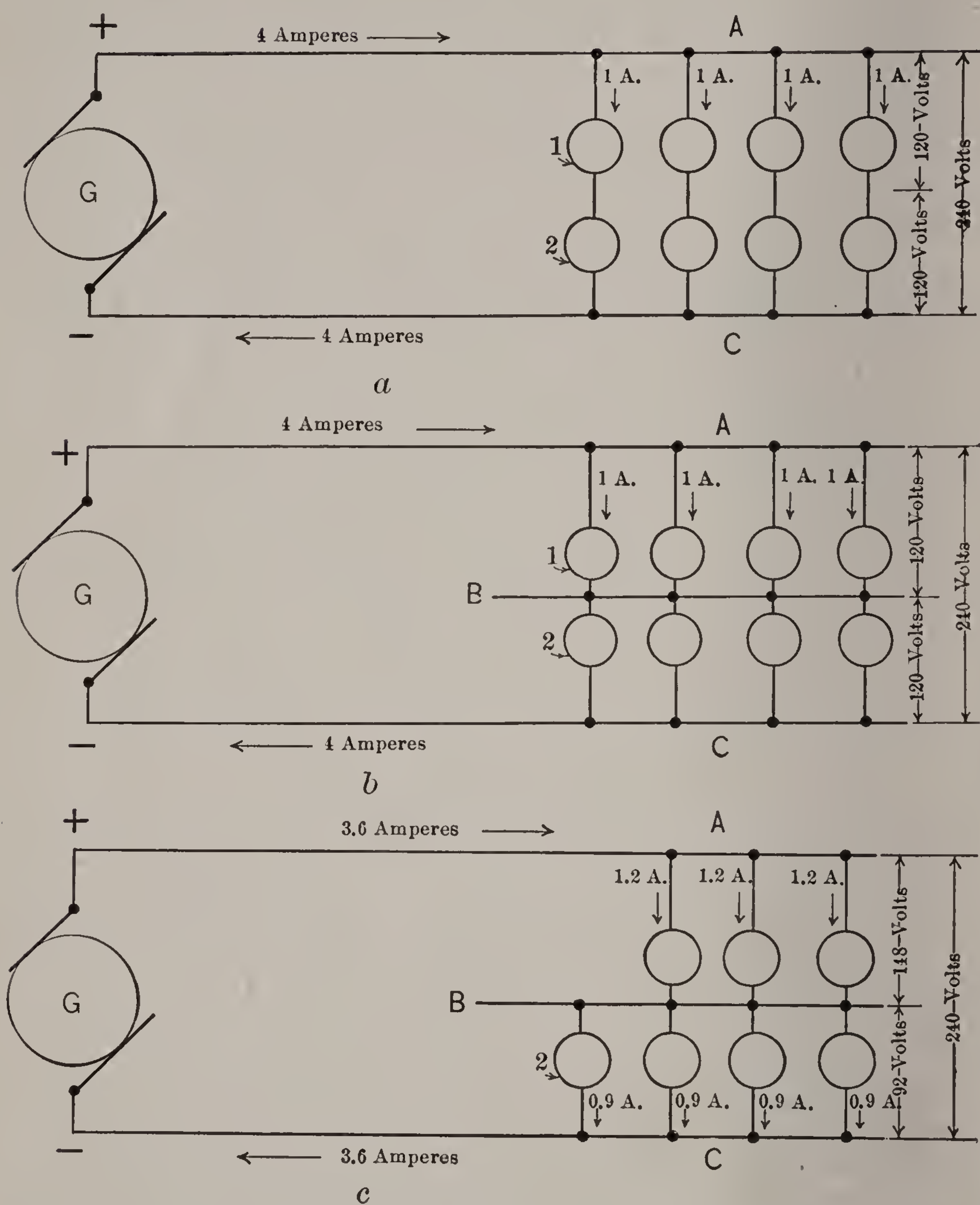


FIG. 110.—Development of the Three-wire System.

In (*c*) it will be noted that each lamp on + side takes 1.2 amperes and on − side 0.9 ampere, although they are all rated at 1 ampere each. This would cause the lamps on the + side to burn out after a short time. Values of voltage and current given are only approximate.

Fig. 110*c*. It is apparent that there are now four lamps on the negative side of the circuit in series with three lamps on the

positive side. Since the same total current must flow in the positive and negative lines, it is apparent that the voltage of the lamps on the positive side would be above and on the negative side below 120 volts. This would cause the lamps on the

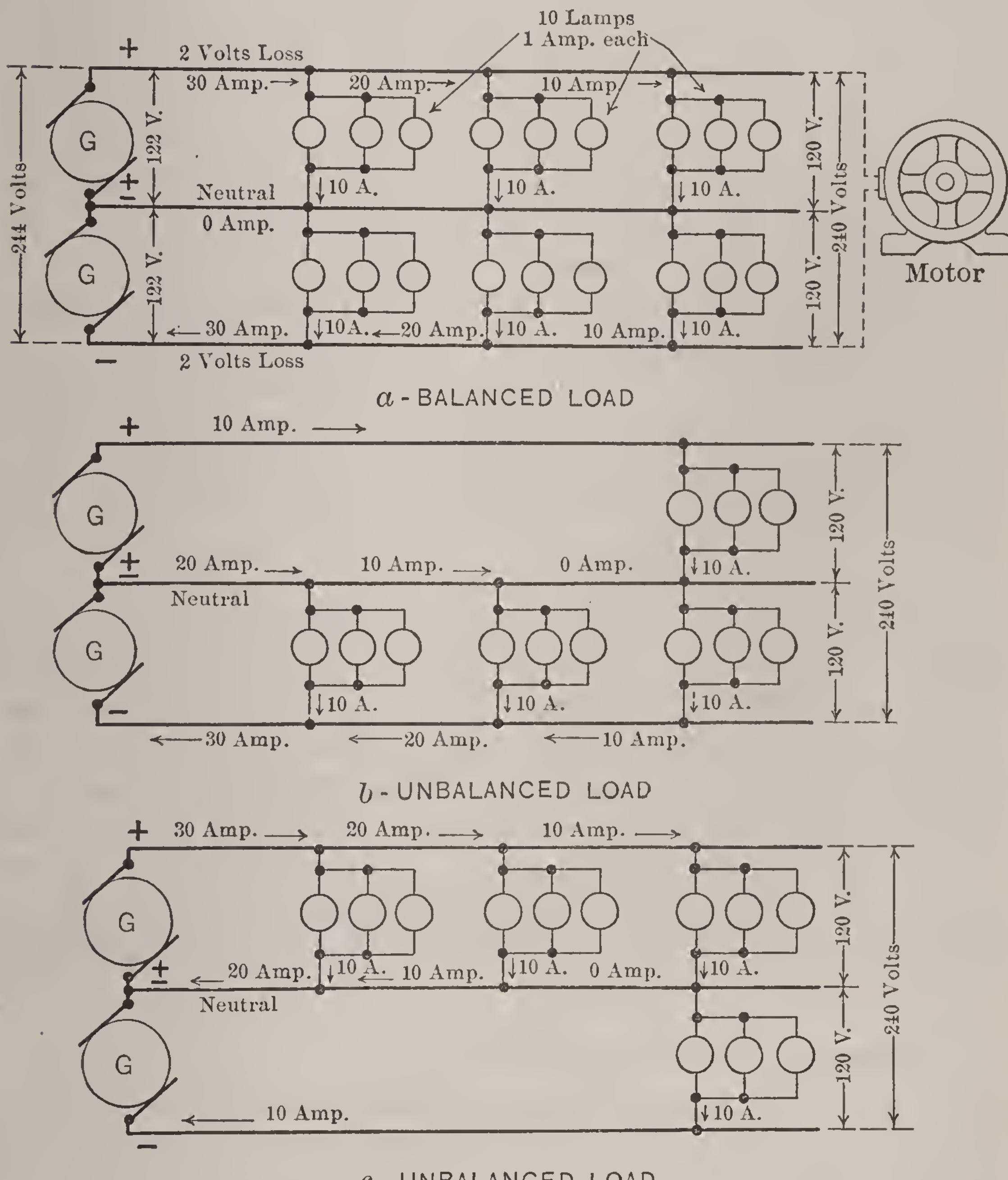


FIG. 111.—Three-wire System.

side having the smaller number to burn above normal candlepower, and those on the other side below candlepower. In fact, with only a small number of lamps on one side, there is always danger of burning out these lamps. The arrangement

shown in Fig. 110*b* and *c* is therefore not practical, and that shown in Fig. 110*a* is not allowed by the National Electric Code. If the wire B is kept at a potential midway between A and C (120 volts in the example), then lamps may be added or removed from either side and the other lamps will not be affected. Such an arrangement is called a three-wire system (Fig. 111). The middle wire, called the **neutral**, is kept at a voltage one-half that between the outside wires by using two generators as shown in Fig. 111, by a balancer set, a three-wire generator or by other methods which cannot be described here. Usually the attempt is made to have equal loads on the two sides, giving a **balanced system** (Fig. 111*a*). Under this condition, the currents in the positive and negative wires are the same and no current flows in the neutral. If the load is not the same on the two sides, the currents in the positive and negative wires are not alike, giving an **unbalanced system.** The neutral then carries a current which is equal to the difference between the currents in the outside wires (Figs. 111*b* and *c*). In the example (Fig. 111*b*) there are ten lamps on the positive side which may be considered to be in series with ten of the lamps on the negative. The current for these lamps flows directly from the positive to the negative terminal of the system. The remainder of the lamps on the negative side must be supplied through the neutral and the negative line. The direction of the current flowing in the neutral reverses when the heavier load is on the positive side (Fig. 111*c*). The load on the positive and negative generators is the same as the load on the corresponding side of the system as is shown by the diagrams. The amount of unbalancing is usually expressed in per cent of the total load.

Example. For Fig. 111*b*, we have:

Load on positive side	10×120	$= 1200$ watts
Load on negative side	30×120	$= 3600$ watts
Total load		$= 4800$ watts
Difference in load		$= 2400$ watts
Unbalancing	$\dfrac{2400 \times 100}{4800}$	$= 50$ per cent

Usually the unbalancing will not exceed 10 per cent. When motors are operated from a three-wire system, they would

in general be connected between the outside wires (as shown by the dotted lines in Fig. 111*a*), so as to use the higher voltage. The advantage of the three-wire system is that the load is in effect transmitted at 240 volts instead of 120 volts, while at the same time it is possible to use 120-volt lamps, which have some advantages over 240-volt lamps. Consequently the size of the feeders can be greatly reduced.* Three-wire systems may be either direct or alternating current, although the former is somewhat more common. The d.c., 240–120-volt, three-wire system, sometimes called the **Edison system,** is used in the business sections of many large cities for distributing electricity from central stations. The d.c. system is also used in many isolated plants, particularly for office buildings, etc. A.c., three-wire systems are used to a considerable extent for distributing electricity from central stations and for lighting circuits for isolated plants.

216. The Three-wire Convertible System. It is apparent from a study of Fig. 111 that if the positive and negative

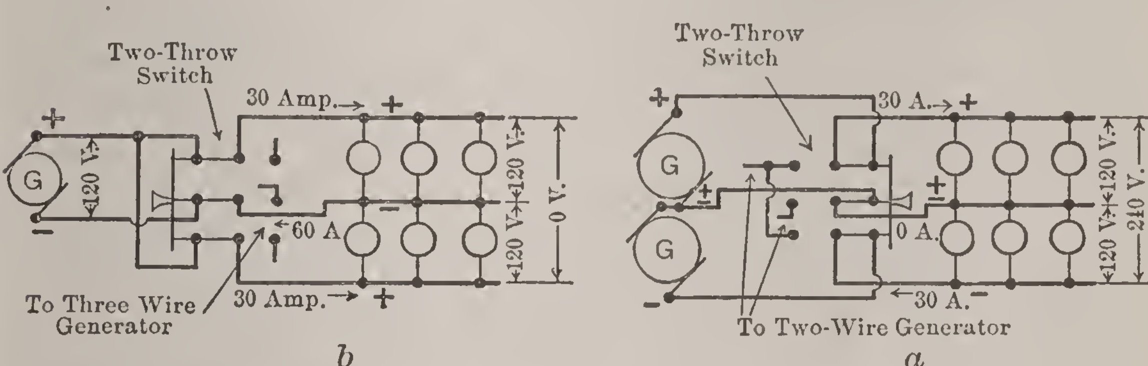


FIG. 112.—Three-wire Convertible System.

a. Connections when operating three-wire. *b*. Connections when operating two-wire. It is important, in the case of arc lamps and Cooper Hewitt lamps, that they shall all be connected on the side of the circuit which does not reverse polarity when operating two-wire.

wires of a three-wire feeder are connected together and the system supplied with the voltage to neutral (120 volts in this case), the lamps may be operated as a plain two-wire system (Fig. 112). This arrangement is sometimes used where the system is intended to be operated either from a two-wire isolated plant or a three-wire central station service. It is apparent that when this system is operated two-wire, the neutral must carry the *sum* of the currents in the other two wires. The cross-section of the neutral is therefore made double the size of one of the

* See paragraph 213.

outside wires. If the feeder is calculated to give the proper drop when operating as a two-wire system, it would require just as much copper as a regular two-wire system of the same voltage. The cost, however, would be greater, since all the switches and panel boards must be three-wire and since the cost of three wires is more than the cost of the same cross-section of copper when combined into two wires. When such a system is operated three-wire, the percentage drop will be one-half as much as when operated as a two-wire system.* If arc lamps are used on this system, they must all be connected between one of the outside wires and the neutral unless a reversing switch is provided. This is to prevent the reversal of polarity which occurs when the system is changed from three-wire to two-wire. Motors used on such a system may be connected between the neutral and either outside wire, since a reversal of polarity would not affect them. The result is, however, that 115-volt instead of 230-volt motors must be used, with the resulting increase in copper for the branch circuits. There is in fact no justification for adopting a system of this kind for a new installation (unless it is very small), since there are at least two very satisfactory methods for operating a three-wire, d.c. system from an isolated plant. The cost of a convertible system is much greater than a three-wire system, and is considerably more than a plain two-wire system. There are no attendant advantages, since a 240–120-volt, three-wire system allows the use of 120-volt lamps and 240-volt motors, thus giving the most desirable arrangement for each class of service.

217. The Three-phase System. This is an a.c. system which has three equal phase voltages and uses either three or four wires. The **three-wire, three-phase system** (Fig. 113) has equal voltages between any two wires of the circuit. Lamps are connected between two of the line wires, and motors (shown by dotted lines) are connected to all three line wires. Usually the lamp loads are distributed equally across the three phases so as to give a **balanced load.** Motors would always give a balanced load. If the load is balanced, the current in each line wire is

$$\text{Amperes} = \frac{\text{Total watts}}{\text{Voltage between wires} \times 1.73 \times \text{power factor}}.$$

* See paragraph 318.

Detailed methods of calculating the currents in the various wires are given in paragraph 328. The **four-wire, three-phase system** (Fig. 114) has equal voltages between the three line wires, and also employs a fourth wire called a **neutral.** The relation between the neutral and phase voltages is:

(*a*) Voltage between neutral and any outside wire is 0.577 times voltage between outside wires.

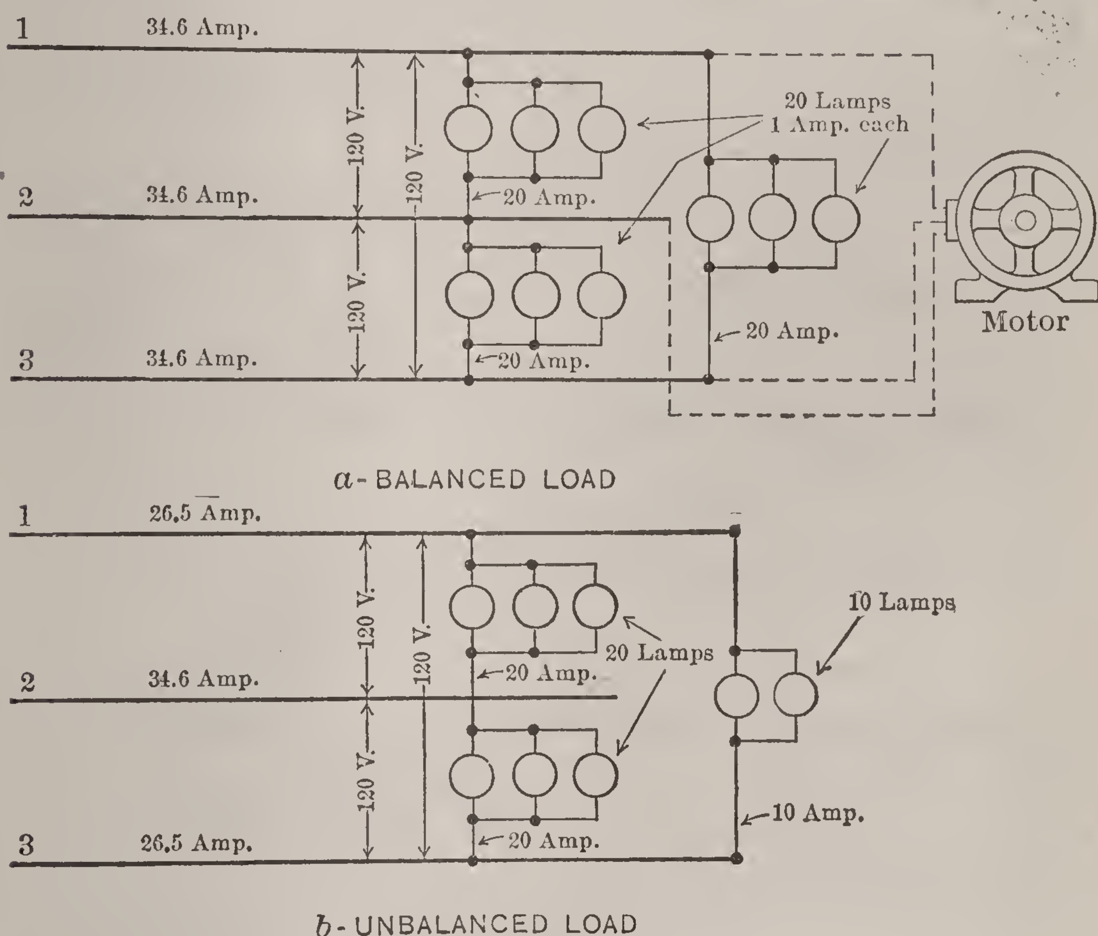


FIG. 113.—Three-phase System.

(*b*) Voltage between outside wires is 1.73 times voltage between neutral and outside wires.

The relations given above are definitely fixed, so that the voltage to neutral cannot be changed without changing the voltage between line wires. Lamps are connected between neutral and outside wires. Motors are connected to the three outside wires and always produce a balanced load. When there is a **balanced load** (Fig. 114*a*) the current in all line wires is the same and no current flows in the neutral.* With an **unbalanced**

* See paragraph 328.

load, the currents in the three line wires will be different and a balancing current flows in the neutral. The advantage of the four-wire system over the three-wire system is that the motors may be operated at a higher voltage than the lamps, thus saving in the cost of the feeders, in spite of the additional cost of run-

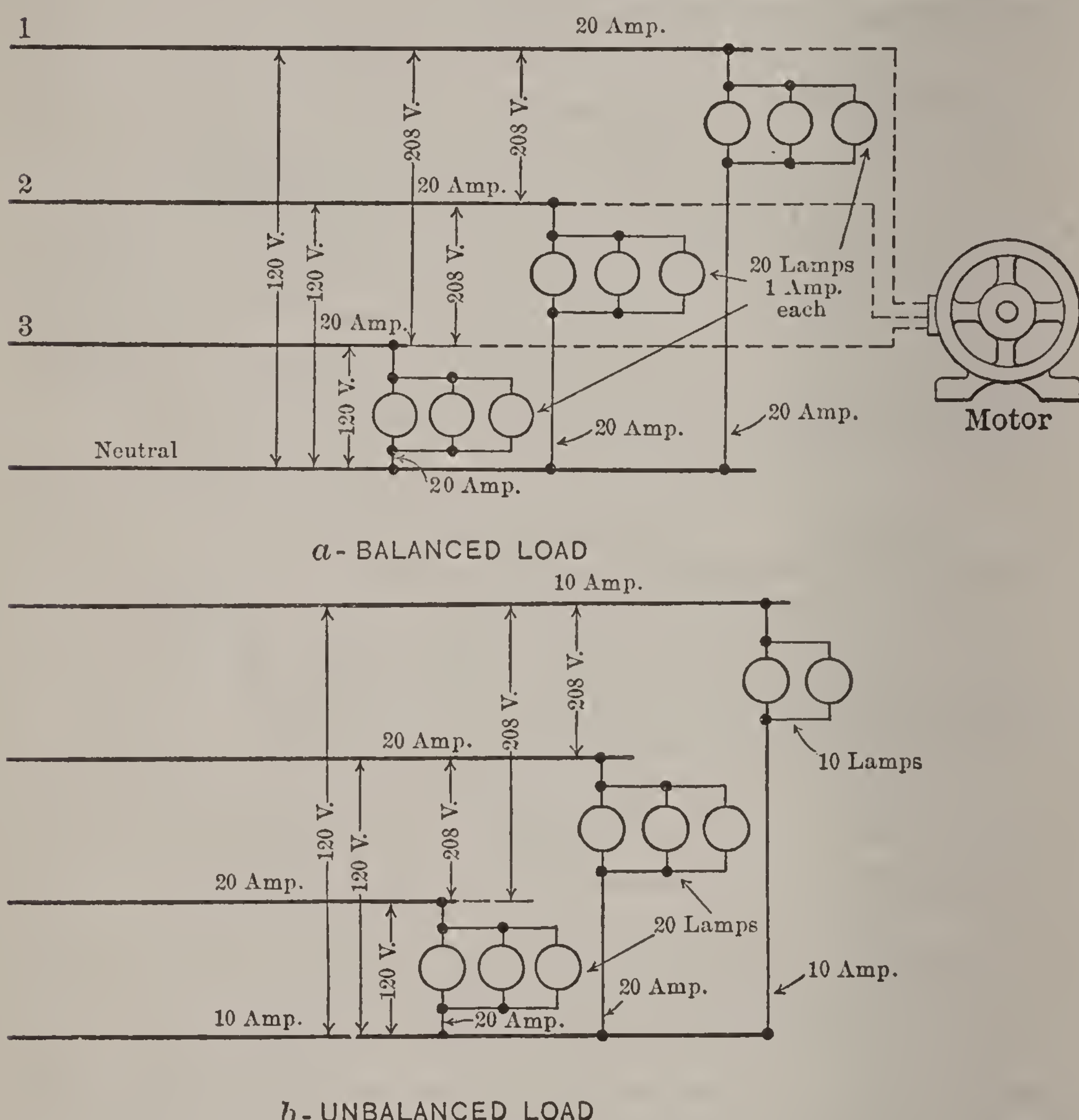


Fig. 114.—Three-phase, Four-wire System.

ning four wires instead of three. For this reason, the four-wire system is used very commonly for distributing alternating current from central stations when both motors and lights are to be supplied. The three-wire, three-phase system is used principally for power supply either from a central station or an

isolated plant and is used in some cases for lighting circuits only.*

218. The Two-phase System. This is an a.c. system which has two equal-phase voltages and uses either three or four wires. **The four-wire, two-phase system** is illustrated in Fig. 115. Two wires are used for each phase. There is usually no electrical connection between the two phases, although they may be supplied from a single generator or transformer. Lamps are connected to each phase as shown in Fig. 115. Motors are connected to all four wires. Since the two phases are indepen-

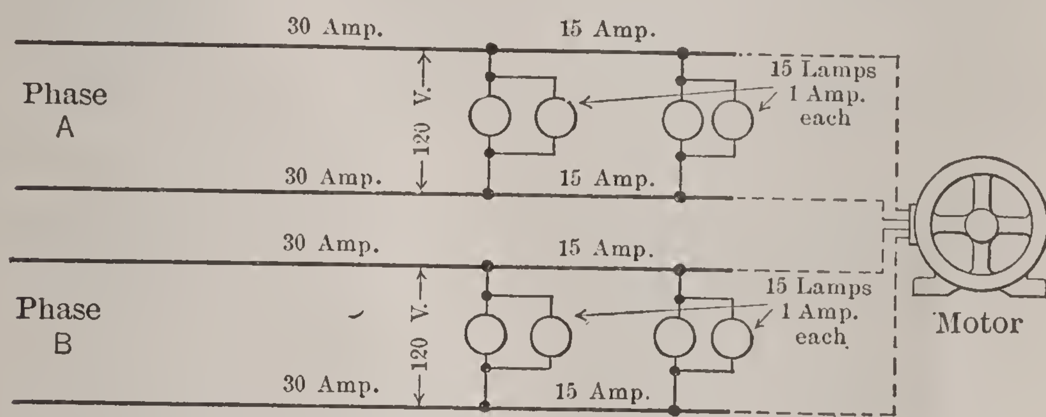


FIG. 115.—Two-phase System.

dent, the circuits can each be calculated like a single-phase circuit. By combining one wire from each phase a **three-wire, two-phase system** is produced (Fig. 116). Between each phase wire and the common wire the voltage is the same, while between phase wires (1 and 2, Fig. 116) the voltage is 1.41 times the voltage to the common wire. Lamps would be connected between the phase wires and the common wire. Motors would be connected to all three wires. For a balanced load and a four-wire system, the current in each wire is

$$\text{Amperes} = \frac{\text{Total watts}}{\text{Voltage between wires} \times 2 \times \text{power factor}}.$$

This formula can also be used to calculate the current in the outside wires of a balanced three-wire system. The current

* A notable example of this is the Pennsylvania R.R. passenger terminal in New York City, where a 240-volt, three-wire, three-phase system is used for supplying the lighting.

in the common wire is 1.41 times the current in one of the outside wires.* The three-wire system requires less copper than the four-wire system,† but the voltage drop in the common wire has a disturbing effect upon both the phase voltages. The system is used more commonly for motor service.

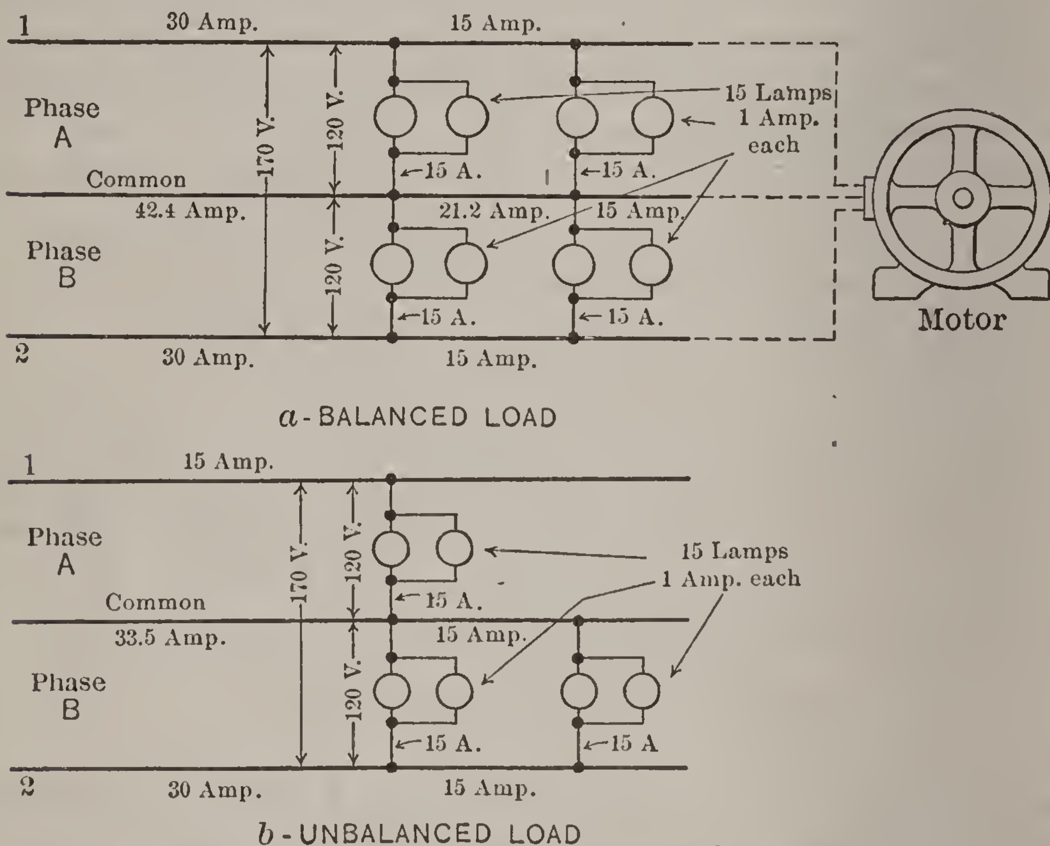


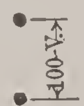
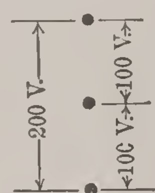
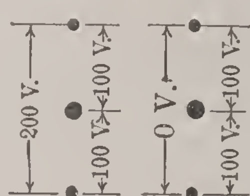
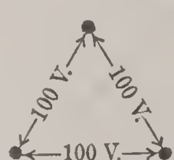
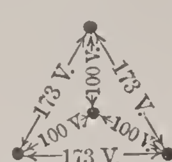
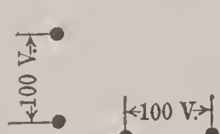
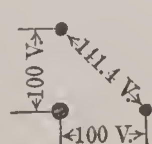
FIG. 116.—Two-phase, Three-wire System.

219. Comparison of Systems. The relative amount of copper required to transmit a given load when using the various systems described in the previous paragraphs is shown by the Table on p. 203. This comparison is based on balanced loads and the same percentage drop is assumed in each case. The voltage at the load is assumed the same in each case. The values given are correct for direct current. For alternating current, especially at low power factors, the percentage drop is somewhat larger. It is not possible, in an actual installation, to obtain all the saving indicated by this table because the total installed cost for a

* See paragraph 329 for methods of calculating current with unbalanced loads.

† See paragraph 219.

Comparison of Systems of Distribution on Basis of Copper Required

System.	Connections.	Voltage Relations.	Relative Amount of Copper in Per cent.
Two-wire, d.c. or single-phase.	Fig. 109		100
Three-wire, d.c. or single-phase.	Fig 111.		With neutral same size as other wires, 37.5 With neutral half size, 31.2
Three-wire convertible, d.c. or single-phase.	Fig. 112		Neutral double size of outside wires, 100
Three-phase (three wires).	Fig. 113		75
Three-phase (four wires).	Fig. 114		Neutral same size as outside wires, 33.3
Two-phase (four wires).	Fig. 115		100
Two-phase (three wires).	Fig. 116		Common 1.41 times as large as outside wires. 73

single large wire is less than for two small wires containing the same amount of copper.

Example. A two-wire No. 0000 feeder will carry a given load at 120 volts with the same percentage drop as a No. 3, three-wire, 240–120-volt feeder. The copper required is:

Two-wire system, $2 \times 212{,}000 = 424{,}000$ c.m.
Three-wire system, $3 \times 52{,}600 = 157{,}800$ c.m.
Relative amount of copper, $157{,}800 \div 424{,}000 = 0.372$.
Cost of No. 0000, two-wire feeder in conduit, \$1.30 per foot.
Cost of No. 3, three-wire feeder in conduit, \$.71 per foot.

It is apparent, however, that there is still a considerable saving in favor of the three-wire system.

220. Choice of Systems for Lighting and Power Service. The **standard voltages** for d.c. generators are 125, 250, and 575, and for a.c. generators 240, 480, 600, and 2300. The system would not necessarily be operated at exactly these values, but might be somewhat higher or lower. The actual operating voltage would be so chosen as to give the correct voltage on the motors. Since incandescent lamps can be obtained for a considerable voltage range (105 to 125 volts for example), they would be selected to suit the actual voltage conditions as fixed by the motor load. It is apparent, from what has been said in paragraph 213, that the voltage of the system should be as high as other conditions will permit. For **d.c. systems** the voltage is limited to 240 volts where incandescent lamps are used. A two-wire, 240-volt system is much cheaper than a 120-volt system, but 240-volt lamps are less efficient and more expensive. The cost of maintenance of the 240-volt system would also be greater because of the higher voltage on switches and sockets. A shock from a 240-volt system is also more serious. The three-wire, 240–120-volt system costs only slightly more than a 240-volt, two-wire system, and has the great advantage that 120-volt lamps and other devices may be used. Where motors only are to be supplied, 240 or even 600 volts may be used if the feeders are very long. A voltage higher than 600 is not satisfactory for industrial purposes because of the danger from shock and the extra cost of the motor control devices. The only applications of the higher voltages are for heavy railway work, where the additional costs are justified by savings in feeders and substation apparatus. Because the voltage is limited to not more than 600 volts for

industrial purposes, direct current is used only where the length of the feeders is comparatively short, as in a single building or a group of buildings located together. It is also used in the business districts of a number of large cities. Direct current must be used for charging storage batteries and for electrolytic work and it is preferable for cranes and adjustable speed motors. When **a.c. systems** are used the ease with which the voltage can be changed by means of transformers makes it possible to take full advantage of the saving resulting from the use of a high voltage. In such cases the power can be transmitted at a high voltage, requiring small-size feeders. At the points of use the voltage can then be reduced by means of transformers to a low value suitable for lamps and motors. The small loss of power in the transformers is more than offset by the saving in the feeders. Here again there are certain limitations to the voltage which should be used. As the voltage is increased the conductors must be better insulated and all switches, transformers and other apparatus would cost more. In a particular problem, therefore, it may be necessary to balance the saving in cost of feeders against the additional cost of the other apparatus. In general, it may be said that for industrial plants 600 volts will be sufficient even for large plants. Sometimes a voltage of 2300 is used, but this is seldom necessary unless the plant covers a large area and considerable power must be transmitted. This voltage is very commonly used by central stations for distributing power to customers. Voltages higher than this are generally used only for transmission of power in large quantities for long distances. The choice of a system is in many cases fixed by the available sources of supply. With a **central station supply**, if **direct current**, the Edison three-wire, 240–120-volt system would generally be employed. Lighting services supplied from these mains would be three-wire, and power services would be two-wire, 240 volts. If an **a.c. supply** is furnished, transformers would be used either for individual customers or for supplying low-voltage secondary mains. For lighting services, a single-phase, 120-volt system would be used for small customers and a 240–120-volt, three-wire supply for larger installations. Small motors would be single-phase and would be operated from the lighting service. Most companies restrict these motors to small sizes because of the serious voltage

fluctuations which they cause. For general motor service 220-volt, two-phase or three-phase systems are commonly used. Sometimes for the supply of a combined load of lamps and motors, a 120–208-volt four-wire, three-phase system is used. **Where the load is supplied from an isolated plant,** for either an industrial establishment, an office building or similar service, there is greater freedom of choice. Even here the possibility of obtaining an auxiliary supply from a central station may have to be considered. The relative size of power and lighting loads will have an important bearing upon the selection of a system when an isolated plant is used. In some cases of light manufacturing, particularly if all the work is in one building, where the feeders would be short, direct current might well be used, employing 120 volts two-wire for small systems, and 240 volts three-wire, or possibly two-wire, for larger systems. If a two-wire system is used, the feeders would be about one-fourth as large for 240 volts as for 120 volts; but, on the other hand, the lighting would have to be supplied at 240, which would entail somewhat greater cost for lamps and maintenance. It is better to operate the motors at 240 volts and supply the lights on a 120–240-volt three-wire system. By this means, the saving in size of feeders is nearly as great as if the entire load were supplied at 240 volts and the advantage of the lower-voltage lamps is secured. The additional power-house equipment required is of small cost. For most industrial uses, a.c. induction motors are satisfactory, and in some cases are almost necessary, either because of the great distances from the power-house or the severe operating conditions due to dust, moisture, etc. The principal disadvantage is the difficulty of adjusting the speed.* A.c. motors are not satisfactory for cranes and elevators, owing principally to the difficulty of control, particularly when making stops. For this reason d.c. motors are to be preferred for high-speed elevators and large cranes. Therefore, in an office building where the elevator load is usually greater than the other motor load and the length of the feeders is not great, the d.c. system is preferable. For large buildings the three-wire, 240-volt system should be used, the motors operating at 240 volts and the lights at 120. Only in small buildings should the 120-volt two-wire system be used. If

* See paragraph 153.

only alternating current is available it would be best to use a.c. elevators unless the speed is high (above 300 ft. per minute) rather than provide the necessary transforming apparatus. For industrial establishments in general, alternating current is to be preferred unless the cranes and adjustable-speed tools form a large proportion of the total load. For the usual **industrial plants**, the three-phase, three-wire system is most commonly used, although two-phase systems are employed to some extent. The voltages may be 220, 440 or 550, but at present there is a tendency towards the use of 440 volts rather than 220 volts, so as to reduce the cost of the feeder system. One disadvantage of all a.c. systems is that the voltage drop on the wiring is greater than for direct current where motors or arc lamps are operated. This is particularly true if open wiring is used.* This disadvantage can, however, be largely offset by the use of a higher voltage, which is feasible with a.c. circuits. A **frequency** of 60 cycles is generally used because it is better than 25 cycles for motors.† In many industrial establishments, as for example, railroad shops which are spread over a large area, alternating current is used for general power supply. The machine tools and cranes which can be operated better by direct current are supplied by means of a motor generator set or a rotary converter. For such service a 120- or 240-volt, two-wire system is generally used.

* See paragraph 322. † See paragraph 164.

CHAPTER 13

METHODS OF INSTALLING WIRING

221. National Electrical Code. All interior wiring should be installed in such a way that it will be protected from mechanical injury and will be safe as regards fire hazard or danger from shock. The apparatus used should be substantially built and suited to the surrounding conditions so as to reduce the cost of repairs to a minimum. Wherever wiring is installed in a building upon which fire insurance is issued (which naturally includes nearly all cases), it is necessary to conform to the rules of the **National Electrical Code**. This code is issued by the National Board of Fire Underwriters and is in effect throughout the United States and Canada. The Code gives definite rules for the installation of all kinds of wiring and also specifies carefully the kind of material (wire, conduit, fuses, etc.) which may be installed. This Code is revised every two years. The National Board of Fire Underwriters maintains laboratories in New York and Chicago where the various fittings and materials used for wiring are tested. Inspectors are also sent to the factories where wire, conduit, etc., are manufactured to see that the material is made in accordance with the rules. All fittings and materials which pass the tests are "approved" for installation under the Code rules and are included in the **List of Electrical Fittings,** which is issued by the Board and is revised twice a year. Unless the device is given in this list it cannot be used where the Code rules must be followed. Most of the material listed, such as conduit, wire, moulding, panel boards, etc., is labeled (Fig. 117). This makes it possible for the user to determine easily if the material is approved. Sockets, receptacles, fuses and similar fittings are not so labeled, but approved fittings can be identified by the manufacturer's catalogue number. Copies of the Code or the List of Fittings may be obtained by applying to the Board of Fire Underwriters at its New York, Chicago, or Boston offices or

to local inspection departments. The inspection department of the Associated Factory Mutual Fire Insurance Companies, with headquarters in Boston, has issued the Code with explanatory notes which give more definite instructions regarding approved methods of installation. This book will be found useful for reference. Most of the large cities in the United States also have more or less complete rules for the installation of electric wiring. They are all based upon the National Electrical Code and in some cases go farther and prohibit the use of certain kinds of wiring which are allowed by the Code. Where local rules exist, they would govern in place of the National Electrical Code, and it is therefore always necessary, when planning an installation, to become familiar with these local rules. In the following, the rules of the National Electrical Code only will be considered and the references given in the description of apparatus and methods are to the paragraphs in this Code (1915 edition) which govern the installation.

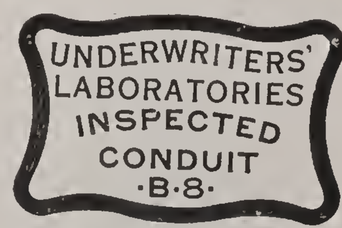


FIG. 117.—Label Used for Approved Conduit.

Labels similar to this are attached to each length of conduit. Other approved fittings are labeled either on the box or on each piece.

222. Types of Wiring. Interior wiring for lighting or power service, at voltages not exceeding 550 volts, may be installed in (1) rigid conduit, (2) flexible conduit, (3) armored cable, (4) moulding, either metal or wood, (5) concealed, on knobs and tubes, and (6) exposed on insulators or cleats. All of these methods are approved by the Code, but the use of some of them is restricted to special places.

Rigid Conduit Systems

223. Description. In this arrangement, a special grade of iron conduit or pipe is installed with suitable bends, couplings, etc., so as to make a continuous wire-way between the outlets, in which the wire may be installed or removed and replaced with very little labor. The conduit may be run on the surface of walls or ceilings or may be concealed in the walls and floors during construction. At each outlet, a suitable outlet box is provided to allow for connecting to the wiring. The advantages of a properly installed conduit system are: (1) the wires

are thoroughly protected against mechanical injury, (2) danger of fire due to short-circuits in the wiring is avoided, (3) the conduit may be made water tight so as to protect the wiring against excessive moisture, (4) the conduit may be placed in a concrete floor or a brick or tile wall during construction of the building and the wires installed later, after the rough building work is finished, (5) damaged wires may be easily replaced at any time without disturbing the conduit system. The disadvantage of the system is its high cost.

224. Applications. A rigid conduit system may be used for all classes of service, but it is chiefly used in buildings of fire-proof construction. It is in fact the only system suitable for such buildings, where the wiring is concealed. Flexible conduit or armored cable may be used in most cases of this kind, but they are not as satisfactory. Rigid conduit is also frequently used for circuits run exposed in power houses and industrial establishments. For the latter class of service, it is especially well suited for the branch circuits leading to the motors and for the lighting circuits. In any place where the wiring is exposed to possible mechanical injury or excessive moisture, conduit systems are very satisfactory.

225. Construction of Conduit. The conduit used for this system must be thick enough to withstand considerable hard usage. It must resist nails, hard blows and should not be flattened by being walked upon or by being run over by wheelbarrows, etc. All this is necessary because the conduit is installed in fire-proof buildings during the construction of the walls and floors and is frequently left exposed a long time, before it finally is concealed. The thickness of the conduit must also be sufficient to prevent burning a hole in the conduit if a short-circuit of the wires occurs. There is always the chance of this occurring, particularly as all kinds of insulation deteriorate with age. The standard conduit (Fig. 118) for rigid systems consists of a mild-steel pipe, having the same dimensions, as regards thickness of wall, inside bore and threading, as the standard wrought-iron pipe used for gas and water piping (Rule 58).* The sizes are designated by the approximate inside diameters. The *act al* inside diameters are, however, slightly greater than the nominal size given. Thus a $\frac{1}{2}$-in. conduit has an inside diameter of $\frac{5}{8}$ in. Table 28

* This and following references are to rules of the National Electrical Code.

gives dimensions of standard conduit. The steel used for conduit is softer than that used for ordinary pipe, so that it can be bent easily. Conduit is furnished in 10-ft. lengths, threaded at each end, with a coupling on one end. Nothing smaller than ½-in. trade size of conduit is allowed (Rule 28*a*). Any size up to 6 in. may be obtained, although a size larger than 4 in. is seldom used. At one time a considerable amount of iron conduit having an insulating fibre lining was used. This is not now approved by the Code. In the manufacture of iron conduit, the pipe is first carefully cleaned of rust or scale and all burrs on the inside are removed. In making the best grades of conduit, the pipe is then coated inside and out with zinc (galvanized) or other protective metallic coating. The inside is then covered with an enamel coating which gives a smooth

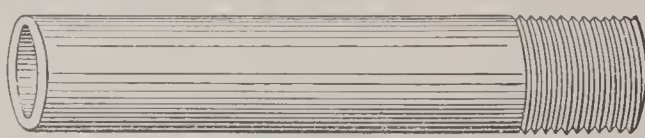


FIG. 118.—Iron Conduit.

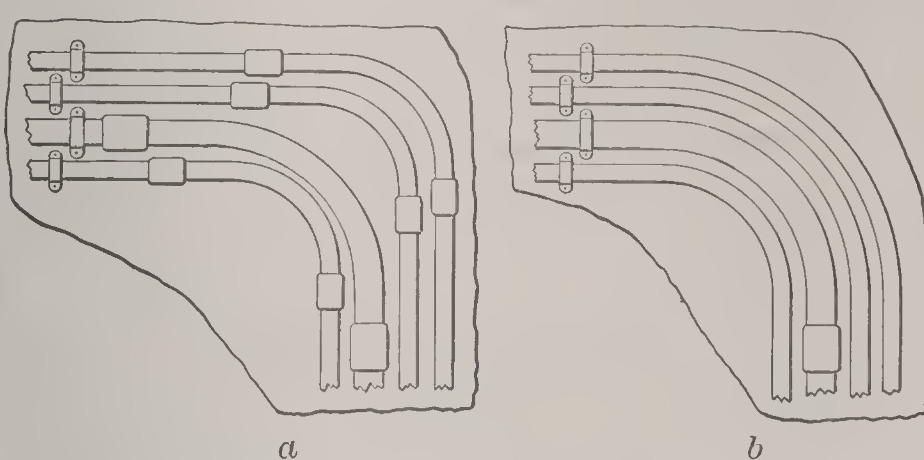


FIG. 119.—Conduit Bends.

a. Installation using standard elbows. *b*. Installation using conduit bent to fit.

inside surface to assist in pulling in the wires. A somewhat cheaper conduit is made in which only an enamel coating is used on the inside and outside. The galvanized is best where exposed to moisture, cement, etc.

226. Conduit Bends. Where a turn is made in a conduit run, the elbow or bend must have a radius large enough to enable the wires to be pulled in without damage. The radius of the

curve of the inner edge of any elbow must not be less than $3\frac{1}{2}$ ins. (Rule 28*h*). The radius must, of course, increase with the size of the conduit (Table 28). **Stock bends** (Fig. 132) may be obtained from the manufacturers for all sizes of conduit, but these are ordinarily not used for $\frac{1}{2}$ or $\frac{3}{4}$ in.-conduits, as these sizes can be easily bent. In exposed work, particularly where appearance is important, it is better to bend all sizes of conduit rather than to use stock bends, because of the better appearance of the work. This is illustrated in Fig. 119. Small sizes of conduit may be easily bent cold, by hand, by the use of a "hickey." To do this (Fig. 120) the hickey is slipped over the pipe to the proper point and then a small bend is made. The hickey is then slipped along

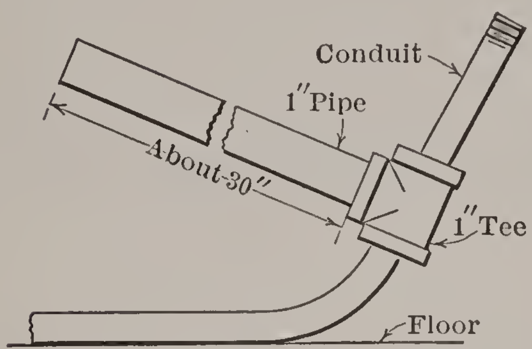


FIG. 120.—Bending Conduit with Hickey.

Home-made hickey consisting of 1-inch pipe Tee and short length of iron pipe. Conduit is held down to floor with the foot, and bend made as desired.

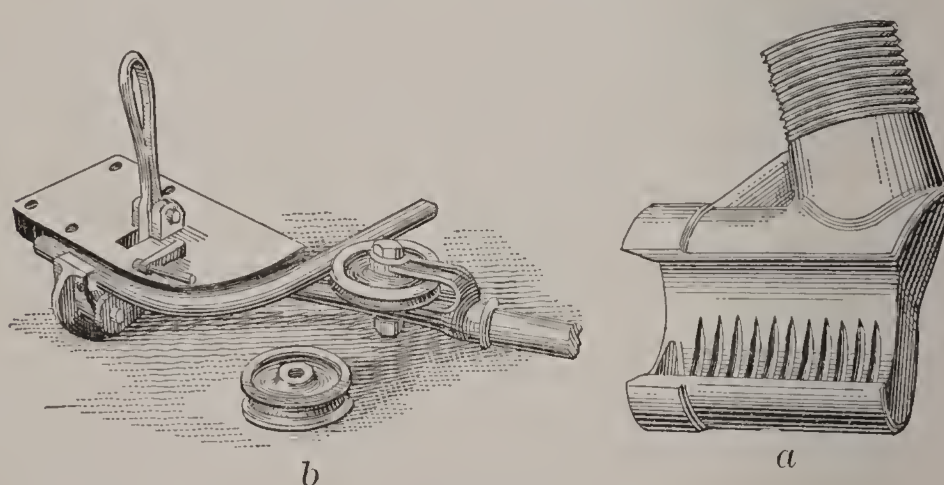


FIG. 121.—Devices for Bending Conduit.

a. Hickey. A piece of 1-inch pipe is used for a handle. *b*. Small bending machine.

further and another slight bend is made. This process is repeated until the required bend is secured. If a considerable bend is made each time the radius will be smaller than if only a slight bend is made before moving the hickey. The exact manipulation to secure the proper bend at the right place

can be learned only by practice. Where a large number of bends are to be made a bending machine (Fig. 121*b*) would be used. Large conduits, even 4 in. or more, may be bent cold if a suitable rig is made for doing the work. If only a few bends are required, however, the cost of building the necessary forms, etc., would be too great, and the conduit could better be heated and bent.

227. Outlets. Wherever there is an outlet, such as a lighting fixture or a switch, a suitable outlet box must be provided

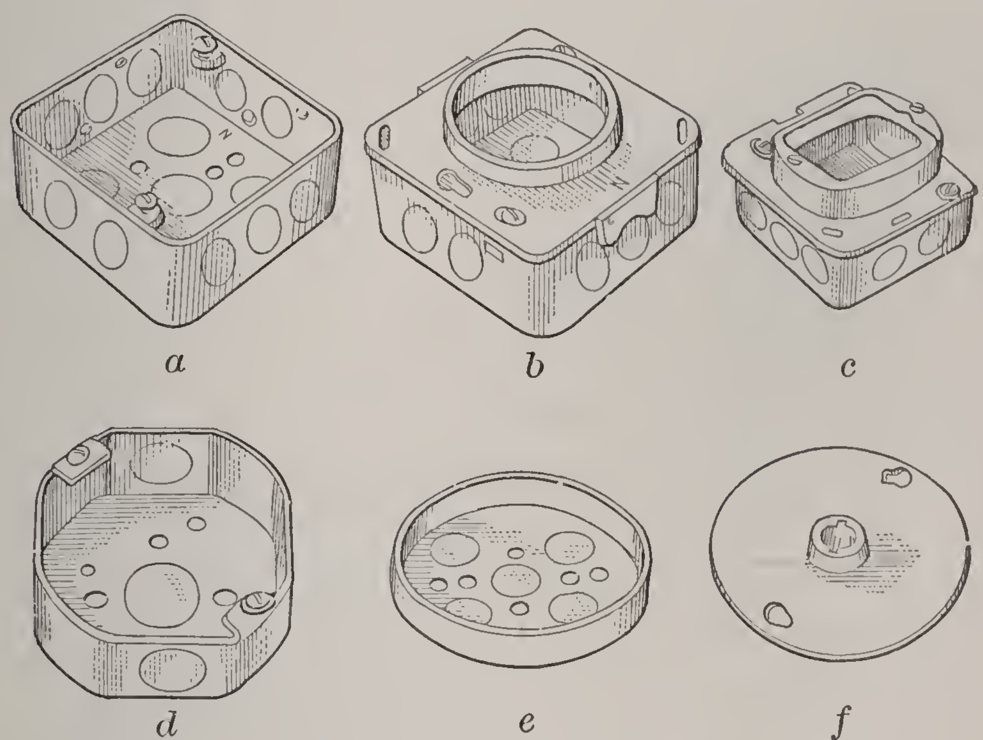


FIG. 122.—Outlet Boxes.

a. 4-inch square box. *b*. 4-inch square box with cover for fixture outlet and knockouts for gas pipe. *c*. 4-inch square box with cover for push-button switch. *d*. 3¼-inch octagonal box. *e*. 4-inch shallow box. *f*. Cover with bushed hole for drop cord.

(Rule 28*d*). These boxes are usually made of sheet steel, although cast-iron boxes are used to some extent, particularly in exposed work. Types of steel outlet boxes, suitable for **concealed wiring**, are shown in Fig. 122. These boxes serve as a terminal for the conduits and also provide a space for making the necessary connections between the circuit wires and the fixture or other device which is attached to the outlet box. When used with switches, they serve to protect the switch parts against injury. They also connect together the

entire conduit system so that it can be thoroughly grounded.* For small fixture outlets, or where only two of three conduits enter the box, a $3\frac{1}{4}$-in. diameter octagonal box is satisfactory (Fig. 122*d*). In some cases $3\frac{1}{4}$ or 4-in. round boxes are used, but these are not allowed in some localities because of the difficulty in making a good connection with the conduit. For switch outlets and larger fixtures, a 4-in. square box (Fig. 122 *a*, *b*, *c*) about $1\frac{1}{2}$ ins. deep is frequently used. A shallow box (Fig. 122*e*) $\frac{5}{8}$ or $\frac{7}{8}$ in. deep is used for outlets attached under floors built of terra-cotta tile or concrete, where the plaster is placed directly on the concrete or tile. The depth of this box allows only for the thickness of the plaster (see Fig. 40). Where the plaster is very thin or where the outlet must be installed on a finished plaster surface, an **outlet plate** is allowed (Rule 28*d*). This consists of a 4-in. diameter plate (similar to Fig. 122*e*) with flanged edges raised about $\frac{1}{4}$-in. All outlet boxes (except the shallow box, Fig. 122*e* and outlet plates) are provided with covers which enclose the box and leave an opening large enough only for the switch or fixture. When fixtures provided with canopies are used, the cover usually has a 3-in. round opening (see Fig. 39). The arrangement of a push-button switch outlet is shown in Fig. 123. Outlet boxes and plates are usually galvanized or sheradized,† although black enamel boxes are also used. In steel boxes, the openings for conduit are provided by means of knockouts, which consist of steel plugs filling the holes and held in place by a small web of metal. A blow of a hammer is sufficient to remove the plug and leave a hole suitable for the conduit. Outlet boxes are provided with a number of knockouts in the sides and bottom, so that the conduit can be installed at the desired point. The size of the knockouts must of course fit the size of conduit used, which is generally $\frac{1}{2}$ in. or $\frac{3}{4}$ in. Knockout plugs must be

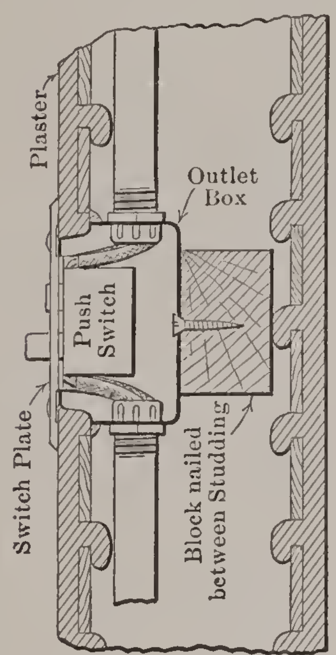


FIG. 123.—Arrangement for Switch Outlet in Partition.

* See paragraph 232.

† Heated in presence of zinc dust. This gives a zinc coating on the surface.

removed only where conduit or gas pipe is to be installed (Rule 59*c*). Outlet boxes are made in a large number of sizes with covers to fit various types of switches and fixtures. The reader is referred to trade catalogues for detailed information on the various types. Where the wires leave an exposed end of a conduit, as for example at a motor, or where the wires are to be continued as exposed wiring (Fig. 127), the conduit must terminate in a suitable bushing (Rule 28*d*). This must provide a separate hole for each wire and each hole must be bushed with an insulating material such as porcelain or moulded composition. There are many forms of such fittings on the market, one kind being shown in Fig. 128. This illustrates only two of the many styles available. In Fig. 224 is shown the use of these fittings for motor wiring. Fittings of this type are also frequently required for the ends of the conduits behind switchboards. In power stations, however, where the board is subject to expert supervision, the ordinary metal conduit bushing (paragraph 228) would generally be accepted. A question of this kind should be taken up with the local inspection department if there is any doubt as to the requirements. In Fig. 129 is shown a method of terminating a conduit for a

FIG. 124.—Switch Outlet.

Three-gang box for three push-button switches (flush type), installed between studding. Box is fastened to a wooden strip nailed to studding.

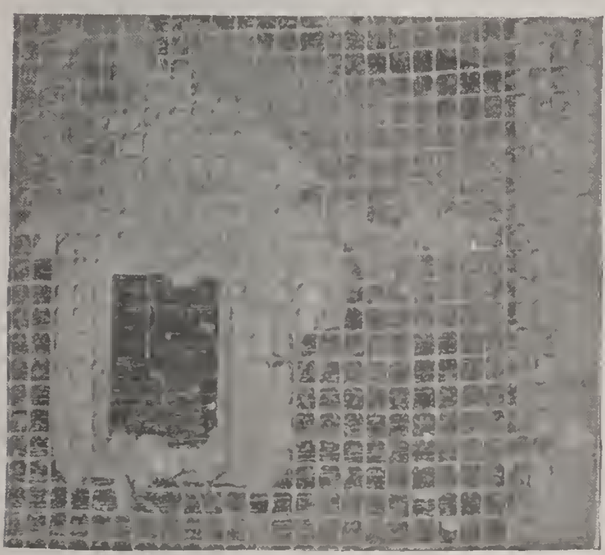


FIG. 125.—Switch Outlet. Ready to plaster in.

Showing wire lath in place over box cover. Outlet is for a single push-button switch, flush type.

circuit entering a building from an overhead line. **For exposed conduit**, sheet-steel outlet boxes are sometimes used, but it is more common to employ cast-iron boxes or special fittings (such as condulets) which are threaded to receive the conduit. These fittings are made in a large variety of styles, suitable for switches, cutouts, lamp outlets, etc., and are very convenient to use and give a good appearance to the finished installation.

FIG. 126.—Ceiling Outlet.

Showing arrangement for a rigid conduit installation where box is located on a floor joist.

While they are somewhat more expensive than ordinary cast-iron boxes, the improved appearance and the saving in the cost of installation offsets this objection. Examples of these fittings are given in Fig. 130. The fittings are now made in styles to suit practically all conditions which may arise. The use of these fittings is illustrated in Fig. 131.

228. Bushings and Locknuts. All ends of conduits must be provided with **bushings** to protect the wire from damage (Rule 28*e*). With condulets and similar fittings the openings

are properly rounded so that no additional bushings are required. In the ordinary sheet steel boxes (Fig. 122), steel bushings must be provided for each conduit end. These bushings are shown in Fig. 132. Bushings of this kind would also be used for conduit which does not terminate in an outlet box and where insulated bushed holes are not required.* **Locknuts** (Fig. 132) are used to make a rigid connection between the steel outlet box and the conduit. Fig. 41 shows a conduit installed in a steel outlet box. Bushings and locknuts are usually galvanized or sheradized. **Couplings** (Fig. 132) are used to join the lengths of conduit and are similar to the couplings used for water piping. Dimensions of these fittings are given in Table 29.

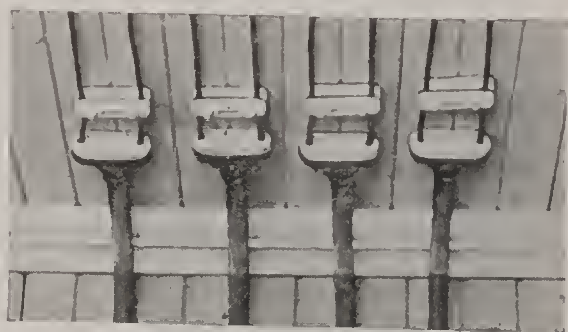


FIG. 127.—Method of Protecting Wires Leaving Conduit.

229. Wire. The wire used in conduit systems must be insulated with rubber and covered with a tough protecting braid. Details of the construction of this wire are given in Chapter 14. For single wires smaller than No. 6, a single braid is allowed (Rule 26n). For twin and multiple conductor wires and for single

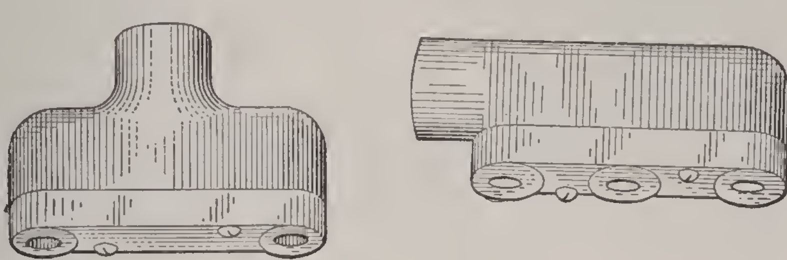


FIG. 128.—Fittings for Bushing Ends of Conduit.
Covers with different numbers of wire holes are manufactured.

wires, No. 6 and larger, a double braid is required. In locations where the wires are subjected to very high temperatures, rubber insulation is likely to be damaged and in such cases, if in dry locations, slow-burning insulation† is allowed by special permission. Wires larger than No. 8 should be stranded, because of the difficulty of pulling large solid wires into conduit and the

* See paragraph 227. † See paragraph 258.

greater likelihood of the insulation of such wires being damaged during the process. The sizes of conduit used for the wires must be large enough to enable them to be installed without damage. The size will depend to some extent upon the length of the run and the number of bends. Not more than four right-angle bends or their equivalent are allowed in a run between two outlets, bends near the outlets not being counted (Rule 28*h*). Table 30 gives the required sizes of conduit for various sizes and number of wires in a conduit. This is based on the use of wire suitable for any voltage up to 600 volts. Wires for higher voltages have thicker insulation and would require larger conduits. The sizes given in this table are the smallest allowed by the Code (Rule 28*i*) and would apply, in general, to runs having not more than three right-angle bends for small wires (No. 10 and smaller) and two bends for larger wires.

FIG. 129.—Wires Entering Building through Conduit.

Showing use of weatherproof bushed fitting at end of conduit. (Factory Mutual Ins. Co.'s.)

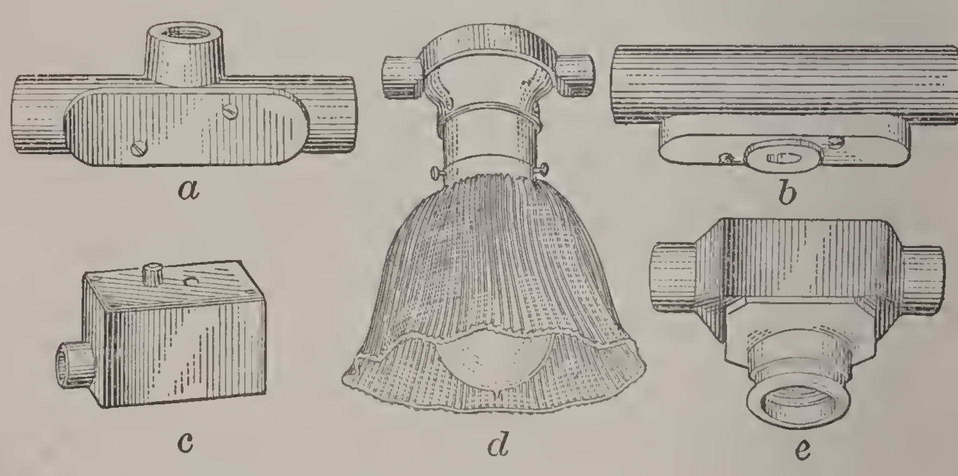


FIG. 130.—Condulets.

a. T-fitting used for junction box. *b*. Outlet for flexible cord pendant fixture. *c*. Push-button switch box. *d*. Outlet for low ceiling. *e*. Receptacle.

If the wire size is the largest specified for a given size of conduit, it would be necessary to go to the next larger size of conduit, where there are more bends or where the length of run is great. An offset bend is especially hard to pull around and should

be counted as two right-angle bends. Where the distance between outlets is very great, it may be necessary to insert a pull-box (Fig. 133) in the conduit run, so that part of the wire can be pulled in at a time. The size of pull-box required would depend upon the conduit size. Table 31 gives sizes of these boxes. The smaller sizes may be made of cast iron, but the larger sizes should be sheet steel. It is a mistake to use too small a conduit. If this is done, the wire may be injured during process of pulling in, and may cause a short-circuit after the system is in operation. Even if this does not occur, the cost of the additional time required to pull in a circuit where the wire fits too tightly will often be much greater than the difference in cost if the next larger size of conduit is used. Not more than four two-wire circuits, nor more than three three-wire circuits are allowed in a single conduit except in special cases. The same conduit must never contain wires of different systems (Rule 26*p*).

FIG. 131.—Example of Use of Condulet Fittings.
Showing use of L-fittings for turning sharp corners.

230. Installing Conduit. The size of conduit is determined by the size and number of wires which it must contain, as explained in the previous paragraph. Where direct current is used each wire can be installed in a separate conduit if desirable, but with alternating current *all the wires of the circuit must be installed in the same conduit* * (Rule 26*p*). It is well to do this even where direct current is used, if there is a chance that the system will be operated by alternating current in the future. If brass, fibre or tile ducts are used, the wires can be separated, but if this is done the voltage drop is increased.† The use of a single conduit for all the wires would

* See paragraph 325. † See paragraph 322.

give a lower cost of installation and would therefore be used except where the size of the wires is so great as to require excessive sizes of conduit.* The conduit system must be continuous between outlets, so that the wire can be installed after most of the mechanical work has been completed, without dis-

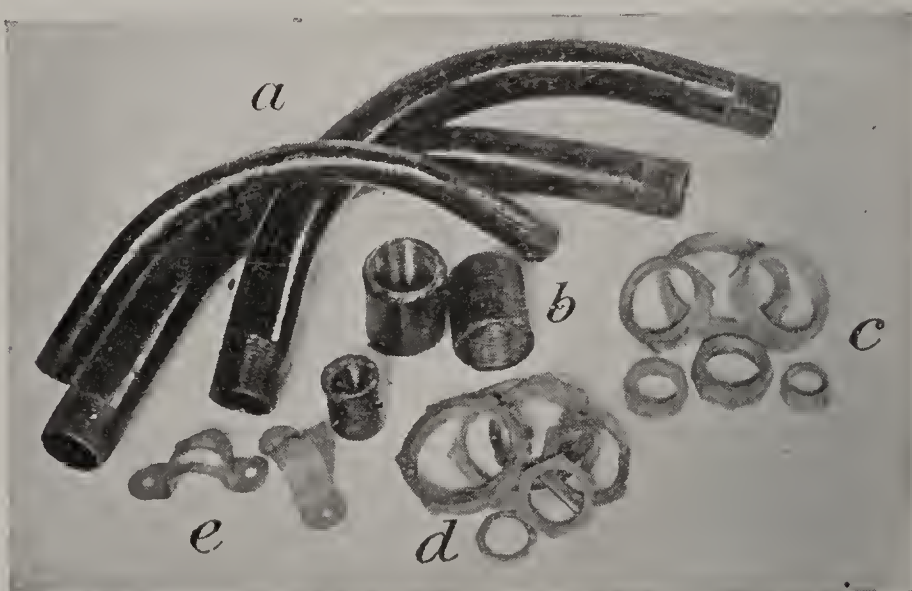


FIG. 132.—Conduit Fittings.
a. Elbows. *b.* Couplings. *c.* Bushings. *d.* Locknuts. *e.* Pipe straps.

turbing the conduit. For concealed work in fire-proof buildings having hollow tile walls and floors, the conduit and outlet boxes are installed before the tile is set. With concrete construction, wooden blocks may be set in the forms at the points where the outlets are to be located and the conduit system installed after the concrete is in place. This arrangement could be used for outlets like those shown in Fig. 38. Another method is to locate the conduit and outlet at the correct place in the forms and pour the concrete over them. This method is illustrated in Fig. 39. The conduit must be properly secured, so that it will not be displaced during construction or when the wire is pulled in. Conduit which is to be buried in concrete

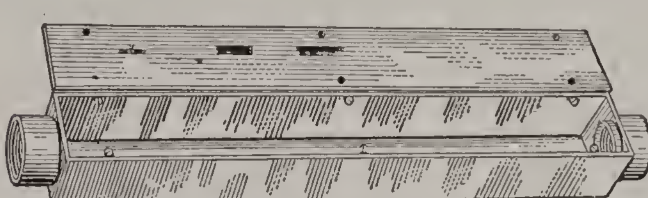


FIG. 133.—Pull Box.

* See paragraph 307.

should be galvanized and the joints made tight by the use of white lead or graphite. In exposed work, **pipe straps** (Fig. 132) are generally used for fastening. Where a large number

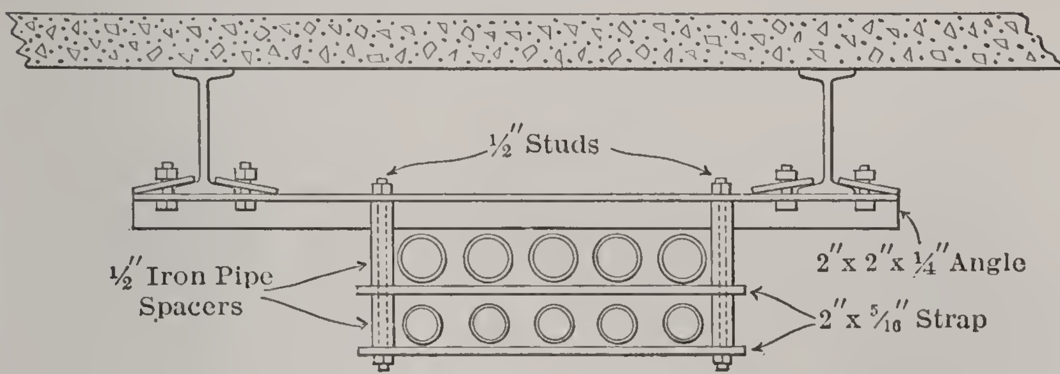


FIG. 134.—Support for Conduit.

of conduits are grouped together some form of hanger (Fig. 134) is convenient. Fig. 126 shows a concealed conduit installation during construction. All wire installed in vertical runs

FIG. 135.—Example of Exposed Conduit Installation.

must be anchored to prevent a gradual downward creeping of the wires, which would put a strain on the connections. The location of these anchors should be in accordance with Table

32 (Rule 26*o*). Supports at these points may consist of approved clamps (Fig. 136) located at the ends of the conduit or in a junction box; or the wires may be carried on porcelain

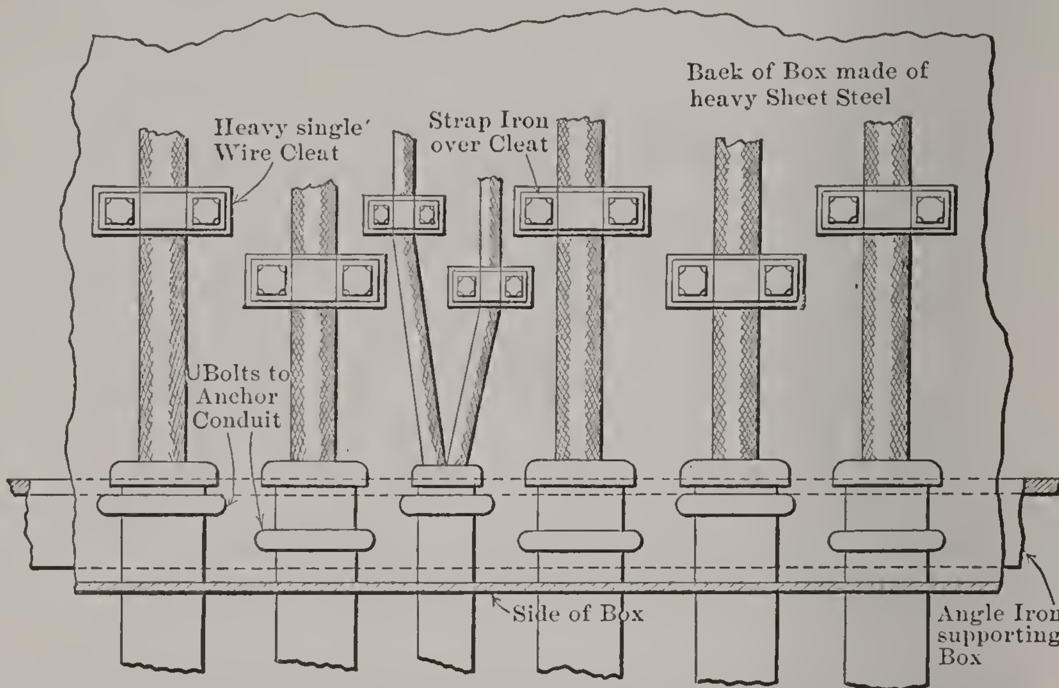


FIG. 136.—Method of Anchoring Vertical Risers.

A steel junction box with extra heavy back is placed in the run. Weight of cables and conduit is carried by angle iron at top and bottom which are bolted to the building frame work. For anchoring risers at end of run, strain insulators similar to these shown in Fig. 172 can be used.

insulators supported in a junction box in such position as to give at least two right-angle bends in the wires.

231. Installing Wire. Small wires may often be pushed through the conduit between outlet boxes, but for large wires

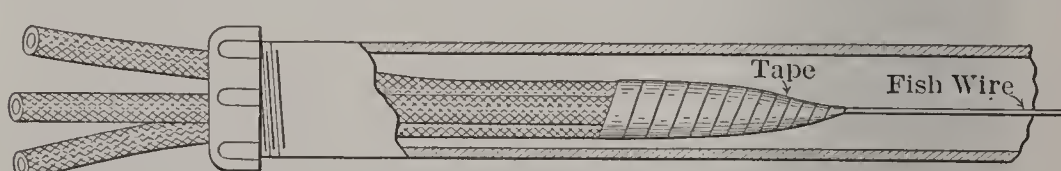


FIG. 137.—Method of Pulling in Wires.

Ends of wires are bared and twisted around a hook in the steel fish-wire. The ends are then taped over smoothly so they will not catch at elbows.

or where there are a number of bends the wires must be pulled in. To do this a steel "snake" or fish-wire may be pushed through the conduit. This snake consists of a flat spring-steel wire, the size commonly used being about $\frac{1}{8}$ in. wide and

0.060 in. thick. The wires, if of moderate size, can be fastened to the end of the fish-wire and pulled in (Fig. 137). For larger wires a steel cable can be pulled through by means of the fish-wire and the wire then pulled in by means of the cable. Where compressed air is available, a cord may be attached to a piece of waste which will fit the conduit snugly, and then this can be blown through by means of the air. The fish-wire or pulling cable can then be drawn through by means of the cord. Before pulling in the wires, a piece of waste should be pulled through the conduit if there is any possibility of water having accumulated in the conduit, due to the condensation of moisture or otherwise. When pulling in the wire, grease or oil should never be used, as it is likely to soften and destroy the rubber insulation after a time. Powdered soapstone or talc can be safely used. Some manufacturers give their small wires a "mica-finish," which helps when pulling in the wire. When several wires are installed in the same conduit, they must of course all be pulled in together. The wires should be free from kinks, and should be fed in straight without twisting around each other.

232. Grounding. All conduit systems must be thoroughly grounded, so that a breakdown of the wire insulation will not charge the conduit to a dangerous potential (Rule 28*f*). Because galvanized conduit makes better electrical connection between the different parts, it is to be preferred to the enameled conduit where other conditions will permit. For the purpose of grounding, the conduit system is connected to a water pipe (on the street side of meter) or to a ground plate. Connection to the pipes must be made by means of ground clamps, one type of which is shown in Fig. 138. Where gas pipes pass through outlet boxes, as in combination electric and gas fixtures, the gas pipe must be firmly connected to the outlet box (Rule 28*f*).

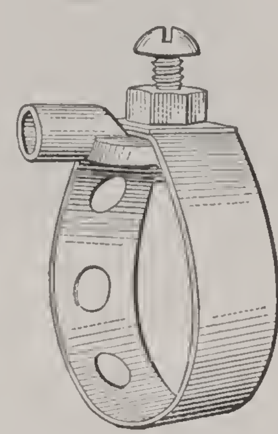


FIG. 138.—Ground Clamp.

FLEXIBLE CONDUIT SYSTEMS

233. Construction and Applications. Flexible conduit is made of steel strips wound spirally, forming a tube with the

edges of the strips interlocked in such a manner that the tube can be bent to a comparatively small radius. In some cases, one, and in other cases two strips are used in forming the conduit. A distinction should be made between *flexible conduit* which is made of steel and *flexible tubing* which is woven from cotton or other fabric, and is non-metallic. The flexible conduit is galvanized to prevent rusting. The construction of one make of this conduit is shown in Fig. 139. The conduit is made in sizes from $\frac{5}{16}$ in. to $2\frac{1}{2}$ ins. nominal inside diameter and in lengths of from 50 to 250 ft., depending upon the diameter. Conduit smaller than $\frac{1}{2}$ in. cannot be used for regular wiring. The smaller sizes are used only for portable and special work. Flexible conduit is sometimes used for exposed work where appearance is of no importance, but it is generally used in concealed work. It is not good practice to

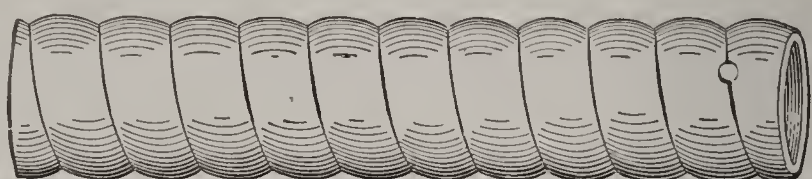


FIG. 139.—Flexible Conduit. (Greenfield.)

build it into concrete floors or walls, but it can be placed in grooves in a brick or tile wall and can be plastered over. Flexible conduit gives nearly as good mechanical protection as rigid conduit, although it is not absolutely nail-proof. As far as protection from short-circuit is concerned it is nearly as good as rigid conduit. The conduit is, however, not water tight and therefore is not as suitable as rigid conduit where exposed to moisture. The chief applications of flexible conduit are in concealed wiring for frame buildings and for extensions to a system in an existing building where rigid conduit could not be installed (Fig. 141). It is also approved by the Code for use in fire-proof buildings, but it is not as satisfactory as rigid conduit for this purpose. Since this conduit is flexible, no elbows are required, but the radius of bends made must be not less than $3\frac{1}{2}$ ins. (Rule 28*h*).

234. Outlets. The rules for rigid conduit as regards outlet boxes apply to flexible conduit also. The same kinds of outlet boxes can be used for either system. Special fittings are used

to connect the flexible conduit to the boxes. Exposed ends of flexible conduit must also be bushed in accordance with the same rules as for rigid conduit.*

235. Conduit Fittings. The lengths of flexible conduit are joined by clamp couplings (Fig. 140). Connections to the outlet boxes are made by means of fittings *c* or *d*. It will be seen that these clamp to the conduit and have standard pipe threads with regular locknuts. No bushing is required, as the edge is rounded over. All these fittings are galvanized.

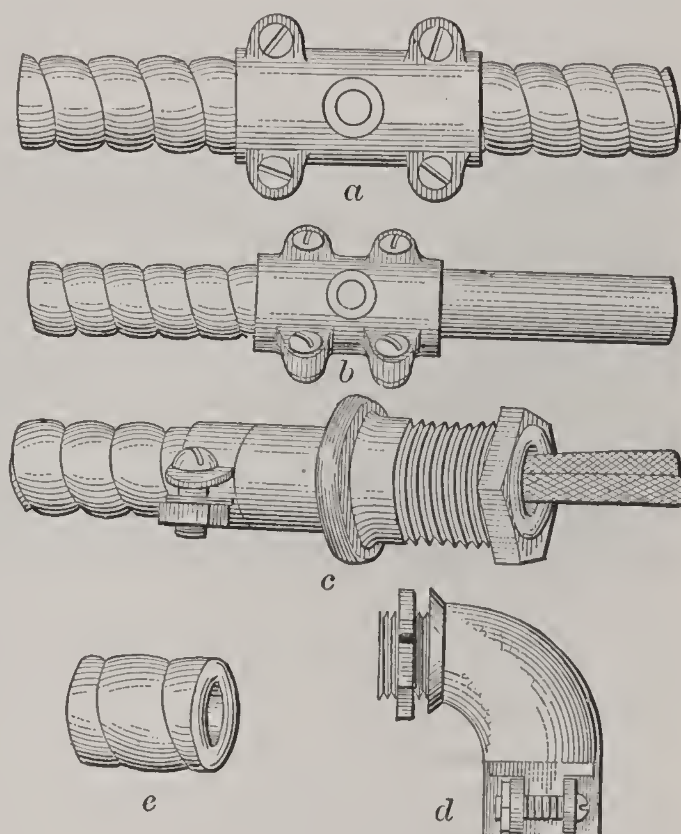


FIG. 140.—Flexible Conduit Fittings.

a. Conduit coupling. *b.* Combination coupling for joining to rigid conduit. *c.* Panel-box connector. *d.* Angle-box connector. *e.* Brass bushing for armored cables. *c* and *d* are also used for armored cables.

236. Wire. The wire used in flexible conduit must be rubber insulated. It is the same as that used for rigid conduit systems. Since the nominal inside diameters of flexible conduit are the same as for rigid conduit, Table 30 can be used to determine the size of flexible conduit required for a given size of wire.

237. Installation. The rule regarding the installation of all wires of an a.c. circuit in the same conduit applies to flexible as well as to rigid conduit. In frame buildings, the conduit can be run concealed in walls and floors, attaching it to the beams or joists by pipe straps. It is important to carefully fasten the bends in at least two points. If this is not done, it will be difficult to pull in the wire, as the bend will buckle and grip the wire. When the conduit is used for concealed work in finished buildings it is "fished" into the space between the

* See paragraph 227.

walls or between the floors and ceiling. This is done by first pushing through a steel "snake" and then pulling in the conduit. For vertical runs, a chain or cord with a weight attached is dropped down until it meets an obstruction, and this is then located by the sound of the chain striking the beam. **When installing the wire** the same methods may be used as for rigid conduit. Vertical runs must be anchored in accordance with

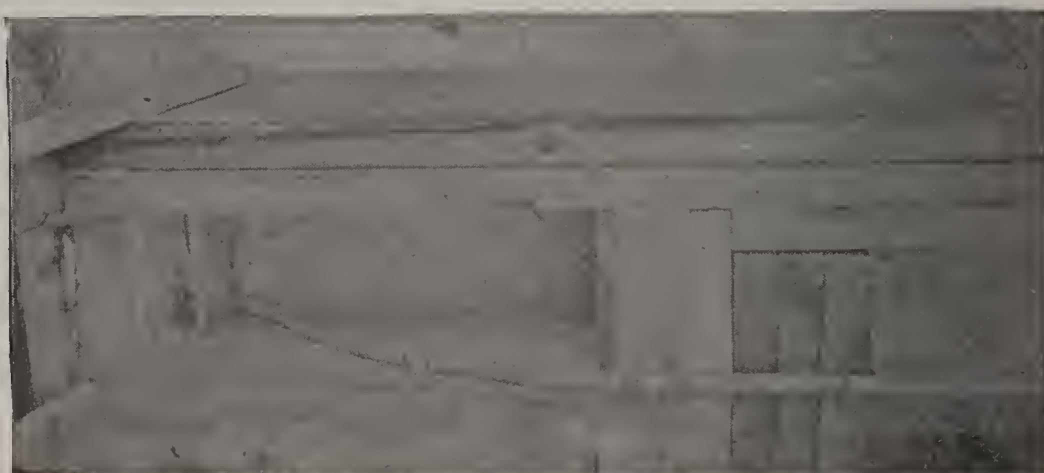


FIG. 141.—Flexible Conduit Installation.

Showing the use of flexible conduit (Greenfield) to extend a rigid conduit system where an outlet must be installed after the walls have been plastered.

Table 32. The **grounding** of the system is accomplished in the same way as for rigid conduit.

ARMORED CABLE SYSTEMS

238. Construction and Applications. Armored cable, frequently called "BX," the trade name of a popular brand of cable, consists of a flexible armor similar to flexible conduit, placed directly upon the wire. This wire is rubber insulated and covered with a braid and is in fact the same kind as that used in metal conduit systems. When the armored cable is installed in damp places or when placed in fire-proof buildings during construction a lead covering is required between the armor and the braid on the wire (Rule 27*d*). Two makes of armored cable are shown in Fig. 142. Armored cables are made with single conductors from No. 14 to No. 1, twin conductors from No. 14 to No. 4, and three conductors from No. 14 to No. 6. They are furnished in coils containing from 100 to

250 ft. In addition, armored flexible cord is also manufactured. Armored cable is used for the same classes of installations as flexible conduit. It is in fact used more commonly than the latter because it is cheaper and easier to install. It gives the same protection to the wire as the flexible conduit, but has the disadvantage that if a breakdown occurs, the entire cable must be replaced, whereas, with a flexible conduit system, the defective wire can be pulled out and new wire inserted without disturbing the conduit system. One advantage of armored cable, as compared with flexible conduit, is that the cable is considerably smaller in diameter, for a given size of conductor, and hence can be fished in places where the clearance is small.

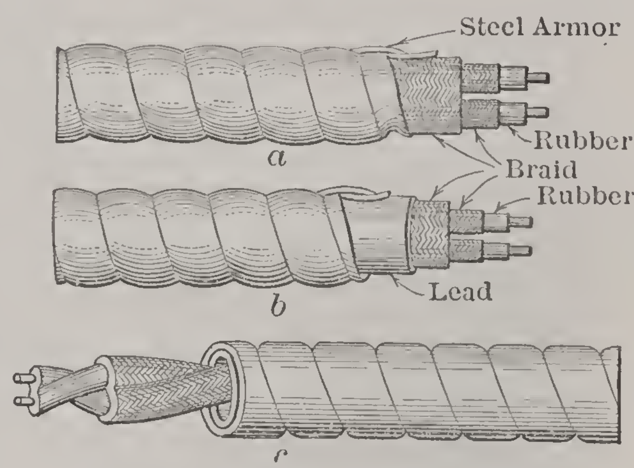


FIG. 142.—Armored Cable.
a. BX cable. *b*. BXL cable (leaded). *c*. Flexsteel cable.

239. Outlets. Outlet boxes similar to those already described (Fig. 122) are frequently used with armored cable. These boxes require fittings like those shown in Fig. 140. Another style of box, arranged to clamp the cable is shown in Fig. 143. No couplings are used with armored cable, as it must be continuous between outlet or junction boxes (Rule 27*a*). The arrangement of outlets is shown in Figs. 144 and 145.

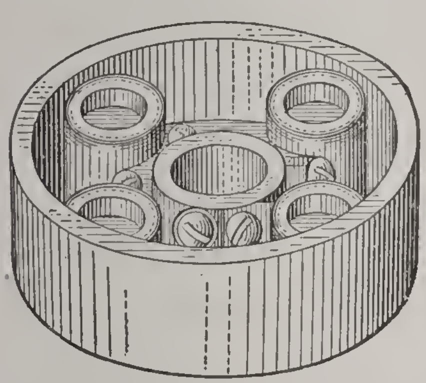


FIG. 143.—Outlet Box for Armored Cable and Flexible Conduit.
The conduit is held firmly in place by the screws shown.

240. Installation. Armored cable cannot be installed in concrete or in permanently damp places unless the wires have a lead sheath under the armor (BXL style). The regular cable can, however, be placed in a groove in a brick wall and covered up by plaster of paris. When armored cable (BX) is used in the

floors or walls of frame buildings it can be run through holes bored in the joists or studding or it may be laid in notches cut in these timbers. The latter method is satisfactory, provided a piece of sheet iron is nailed over the cable at these places to protect it from nails which might be driven into the cable during the process of installing the finished woodwork.

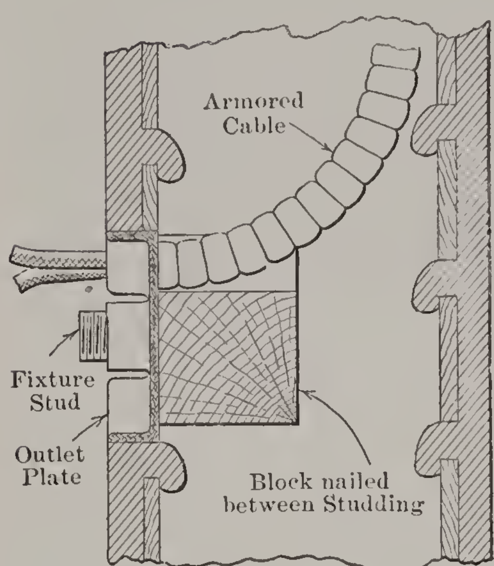


Fig. 144.—Wall Outlet for Lamp Bracket.

Showing 3-in. round outlet box similar to Fig. 143.

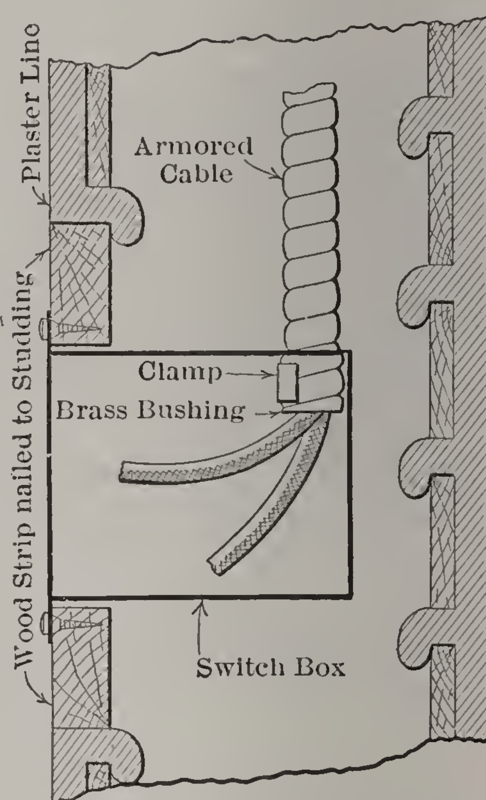


Fig. 145.—Switch Outlet in Wall.

Showing type of box adapted for wiring finished bulidings.

Fig. 146 shows an armored cable installation where the joists were bored.

241. Concentric Wire. Recently experiments have been made with a concentric wire, which is really a form of armored cable. This wire has been used extensively abroad but has only recently been employed in the United States. It is not yet* included in the Code, and is not approved for general use. A few installations have been made, with the consent of the insurance interests, for the purpose of testing the wire in actual service. The wire consists of a single copper

* 1916.

conductor, insulated with rubber, and covered by a metal sheath or armor (Fig. 149). This armor serves as one of the conductors and is carefully grounded for safety. The wire is

Fig. 146.—Armored Cable Installations.

Showing ceiling outlet and armored cable (BX) leading to panel box. Note method of supporting the outlet box.

intended to be used only in exposed locations for small capacity branch circuits. The object of this arrangement is to provide a cheap method of wiring which can be safely used for lighting installations consisting of a few lamps.

Fig. 147.—Wall Receptacle in Tile Partition.

Showing use of armored cable (BX) with square box and cover for flush-plug receptacle. Note box connector used with cable.

Metal Moulding

242. Construction and Applications. This moulding consists of a sheet-steel trough or backing and a steel cover which is snapped on to the backing after the wires are in place. The construction of metal moulding is shown in Fig. 150. Both backing and capping are galvanized to prevent rusting. Since moulding is used for small circuits,

only one size (large enough to contain four No. 14 wires) is made. The moulding is furnished in $8\frac{1}{2}$-ft. lengths. Metal moulding can be used only for exposed work and cannot be used in damp locations or for systems using more than 300 volts (Rule 26*l*). It cannot be used in elevator shafts (Rule 16*g*). Not more than four No. 14 wires are allowed in the same moulding and no single circuit so installed may carry more than 1320 watts (Rule 26*l*). The advantages of metal moulding lie in the simplicity of its installation and the accessibility of the wires. It is used chiefly for extensions of branch circuits in existing installations, or where there is a possibility of changing the branch circuits frequently due to changes in the arrangement of the equipment in the room. Special outlet fittings are manufactured for use with metal moulding. A few styles of these are shown in Fig. 151. The various lengths of moulding are attached firmly to the outlet fittings by means of screws, in order that all parts of the system may be thoroughly grounded. The figure shows some of the fittings used for making taps, turning corners, etc. The wire used may be either rubber insulated,

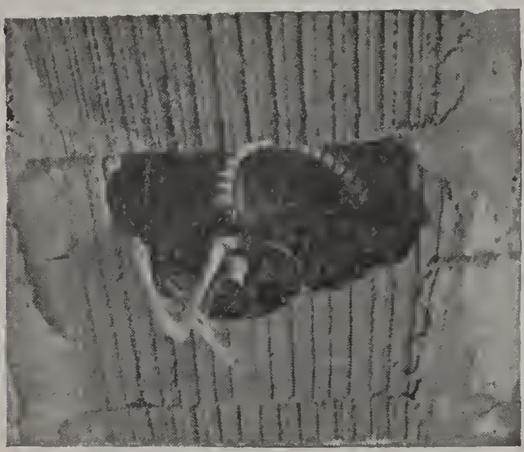


FIG. 148.—Outlet on Tile Ceiling.
Showing use of outlet plate and box hanger with armored cable (BX).

FIG. 149.—Concentric Wire.
(General Electric Co.)

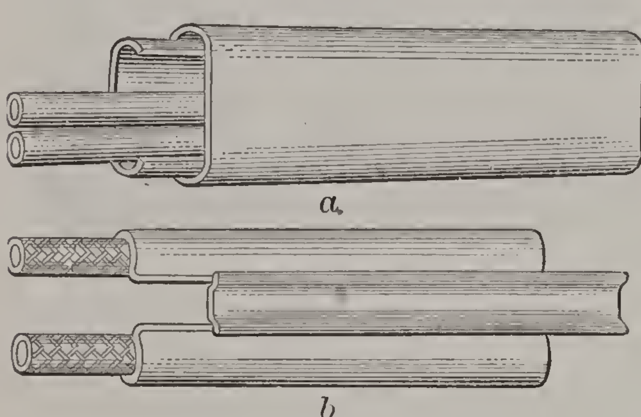


FIG. 150.—Metal Moulding.
a. "National." *b.* "Pagrip."

single conductor, single braided or rubber insulated twin wire.

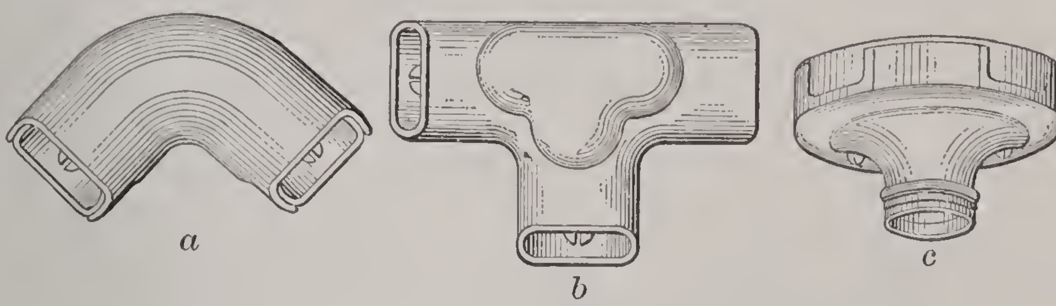


FIG. 151.—Metal Moulding Fittings.

a. Elbow. *b*. Tee. *c*. Receptacle. The moulding is attached to the fittings by the screws shown in the illustrations.

243. Installation. Metal moulding may be cut with a fine tooth hack saw or may be marked with a three-cornered file and broken. If the capping is in place, the moulding may, with care, be bent to any radius not less than 4 in. Special tools are made by the manufacturers for cutting the moulding and punching the screw holes. These tools save a great deal of time. The backing is secured to the ceiling or wall by wood screws or toggle bolts; the wire is laid in the backing and the capping snapped into place. When the moulding passes through a floor it must be protected by an iron pipe extending from the ceiling line to a point at least 3 in. above the floor (Rule 29*b*). Where the moulding passes through a partition, a pipe is not required, provided the surroundings are dry and the moulding has no joint inside the partition. Fig. 152 shows an installation of metal moulding. All parts of the moulding system must be thoroughly **grounded** as described for metal conduits.

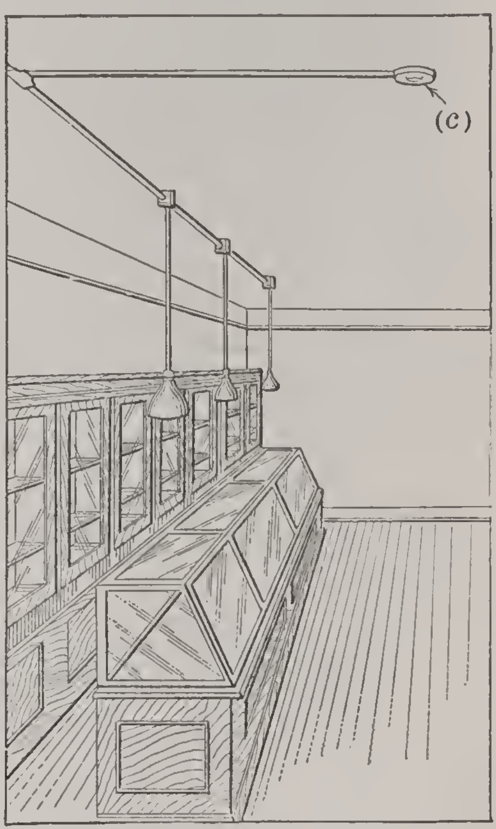


FIG. 152.—Metal Moulding Installation.

A single ceiling outlet (*c*) is replaced by several pendants over counter. (Nat'l Metal Molding Co.)

Wood Moulding

244. Construction and Applications. Wood moulding consists of a backing with grooves to contain the wires and a capping which is nailed to the backing after the wires are in place. The Code recommends the use of hard wood moulding, but generally soft wood is used. The cost of hard wood moulding is nearly twice that of soft wood. Fig. 153 shows the construction. Moulding is made for two wires and for three wires, in sizes from No. 14 to 400,000 cir. mils. The size holding wires up to No. 12 is most commonly used. The wires must be separated by a tongue at least $\frac{1}{2}$ in. thick and the moulding must be painted or shellacked inside and outside

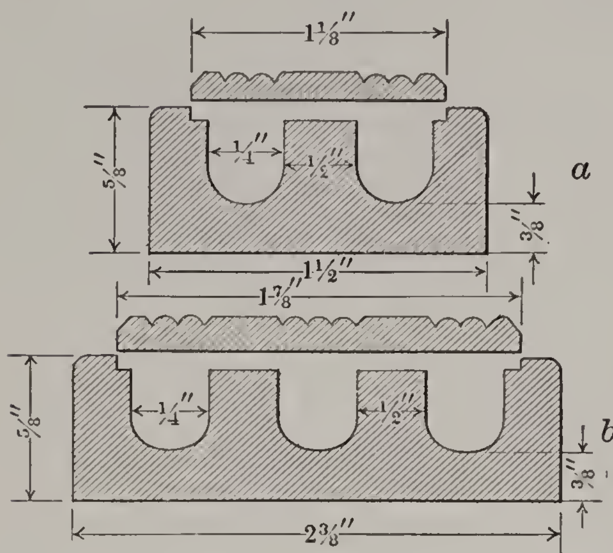


FIG. 153.—Wood Moulding.
a. Two-wire. *b.* Three-wire. Sizes shown are for No. 14 or 12 wire and are those most commonly used.

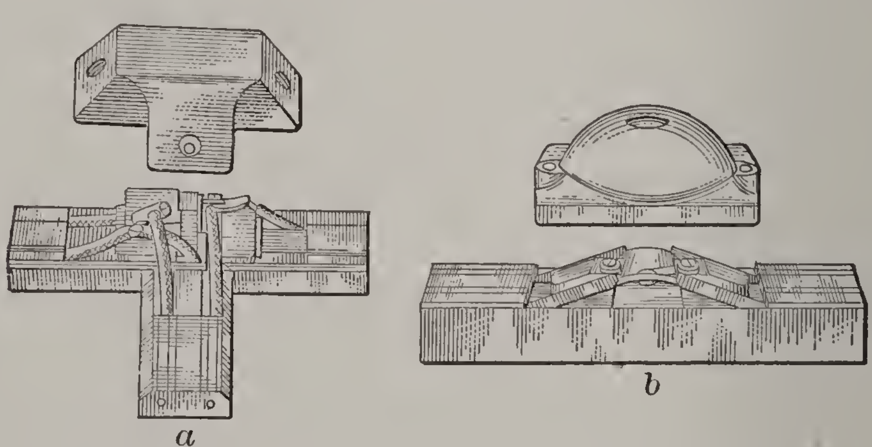


FIG. 154.—Fittings for Wood Moulding.
a. Tap. *b.* Rosette.

to exclude moisture. Wooden moulding can only be used for exposed work. It is not allowed in damp places, in elevator shafts (Rule 16*g*), or for systems operating at more than 300

volts (Rule 26*l*). Wood moulding is often used for extensions of branch circuits in existing installations. In wiring old buildings, wood moulding is sometimes used on the ceilings, with flexible tubing or armored cable where the wires are concealed in the walls. Wood moulding is cheaper than metal moulding but in general it is not as satisfactory. Its use is forbidden by the local rules of some of the large cities. Because of its large size, wood moulding is usually more conspicuous than metal moulding, unless it is combined with the trim of the room. By the use of special capping to imitate picture moulding or by arranging it in panels on the ceiling it can be made less conspicuous. For outlets, porcelain receptacles or rosettes are used. Taps or cross-overs must be made by means of special fittings (Rule 26*k*), (Fig. 154). Rubber-insulated **wire** must be used in moulding (Rule 26*k*). Wood moulding cannot be run through floors or partitions. In such cases, the wires must be run in iron pipe or porcelain tubes (Rule 16*d*). Where the wires enter the moulding, if at the floor line, a wooden or steel box ("kick block") (Fig. 155), must be placed around the wires to protect them from injury.

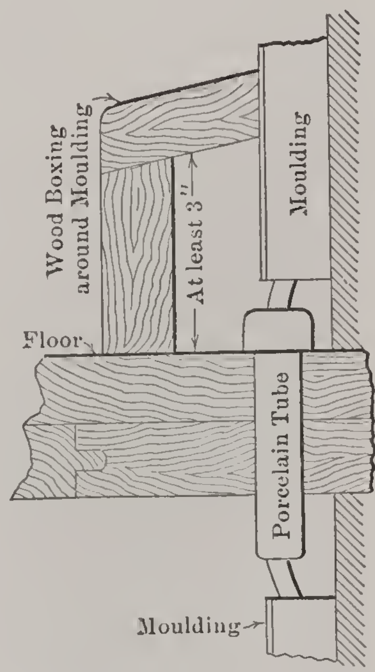


FIG. 155.—"Kick Block."
For protecting wires installed in wood moulding when passing through floor.

KNOB AND TUBE SYSTEM

245. Description and Application. The cheapest form of concealed wiring is the knob and tube system. The wires are run beneath the floors or in the partitions and are supported on porcelain insulators or knobs where the wires are run parallel to floor joists or studding, and pass through porcelain tubes where crossing beams, partitions, etc. Figs. 156 and 157 illustrate this type of wiring. The system is used chiefly in frame buildings (dwellings, etc.), where a cheap piece of work is desired. The use of the knob and tube system is prohibited by the local rules of many large cities. It cannot be used for

fire-proof buildings or for damp places. With this system, the wires are not protected from mechanical injury, and there is always the possibility that they may be damaged by workmen during construction or by rats after the house is in use. The wires may sag against beams, lath, etc., or they may be covered by shavings or other inflammable material during construction so that an overheating of the wires or a short-circuit might start a fire. **The knobs** may be either solid or split (Figs. 158*a* and *b*), and must keep the wires at least 1 in. above the surface wired over. Knobs are generally held by wire nails using a leather washer or nail head to prevent breaking the knob. **The**

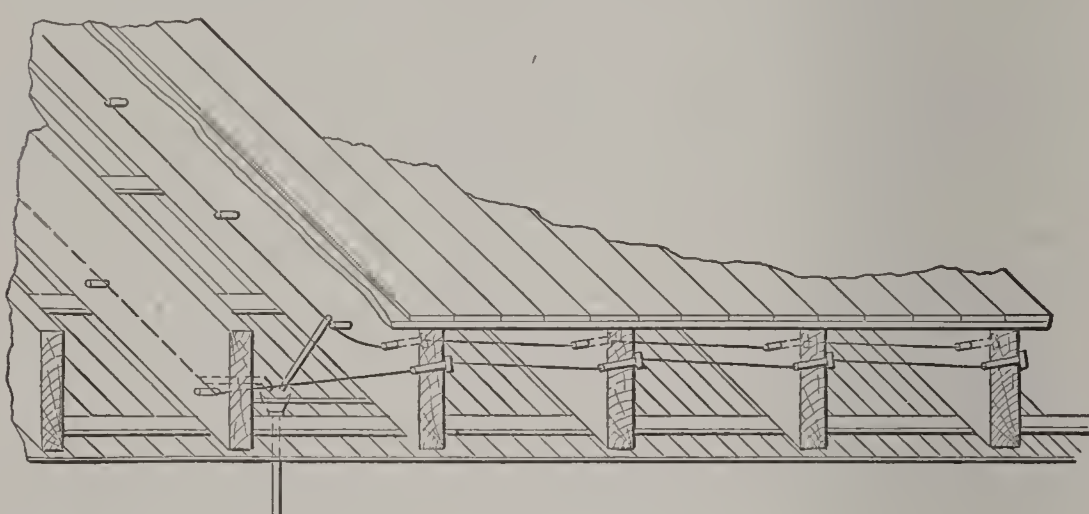


FIG. 156.—Knob and Tube Wiring under Floor.

tubes have a head at one end to prevent their being displaced (Fig. 158*c*). The wire used must be rubber-insulated, with single braid up to No. 6 gauge and double braid for No. 6 and larger sizes. **No outlet boxes** are required, although steel outlet boxes or plates are recommended (Rule 26*u*) (see Fig. 157). At all outlets, the wire must be protected by flexible tubing (Fig. 159), which extends from the last knob to at least 1 in. beyond the surface (see Fig. 34). A similar arrangement is required for switch outlets. If flush switches or receptacles are used they must be enclosed in steel boxes (Rule 24*d*). The wires must be kept as far apart as possible, separated, at least 5 in. and run on different studding wherever possible (Rule 26*r*). The wires must be supported at least every 4.5 ft. and at shorter intervals if they are liable to be disturbed. At outlets and

panel boxes, where the 5-in. separation cannot be maintained, the wires must be covered by flexible tubing (Fig. 157). Where it is impossible to use insulators, the wires may be fished if each is separately incased in flexible tubing (Rule 26*s*). For wires carrying more than 300 volts or for damp places, flexible conduit or armored cable must be used. The **flexible tubing** used is sometimes called "circular loom." The construction differs slightly with various manufacturers, but essentially it consists of a seamless tube built up of braided coverings combined with a closely wound cord or flat paper strip and thoroughly impregnated with a waterproof compound (Fig. 159). Flexible tubing will resist considerable abrasion, but is, of course, not nail-proof and is easily crushed.

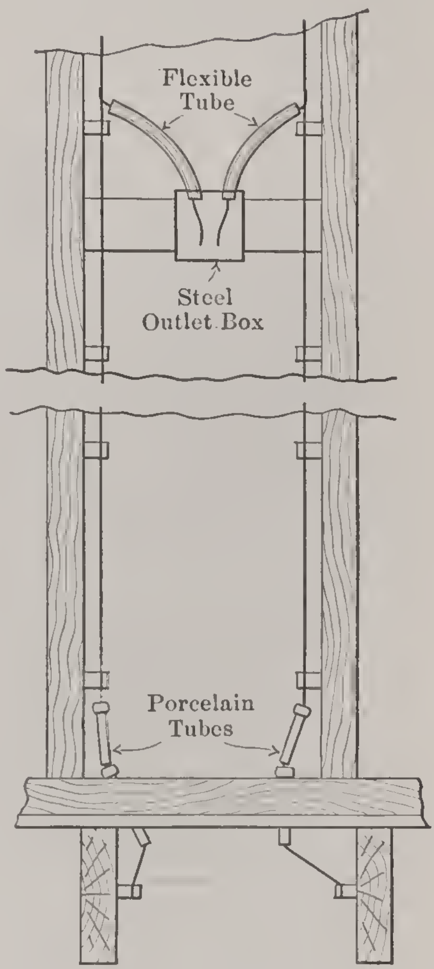


FIG. 157.—Knob and Tube Wiring in Partition.

Extra porcelain tubes must be placed over wires at floor line to protect them from plaster dropping down during construction.

OPEN WORK

246. Description and Applications. In open work, the wires are run exposed, supported on porcelain knobs or cleats. This system is used for small branch circuits, where appearance is of no importance, as in cellars, and is also used frequently for heavier circuits, for factories. In such cases, the feeders and mains are run near the upper part of the room or on the ceiling where they are not likely to be damaged. The branch circuits, which are subject to possible injury and displacement, are run in conduit. This arrangement is much cheaper than where conduit is used throughout, and in many cases is just as satisfactory. The advantages of open wiring are that it is cheap and accessible and can be easily changed as required. On the other hand, the wires are not protected, and are liable to mechanical injury.

247. Cleats and Insulators. For wires smaller than No. 8, split knobs (Fig. 158) or cleats must be used (Rule 16*b*). For larger wires solid knobs may be used, but the better arrangement is to use suitable cleats. For small branch circuits, up to about No. 10, two- or three-wire cleats are generally used

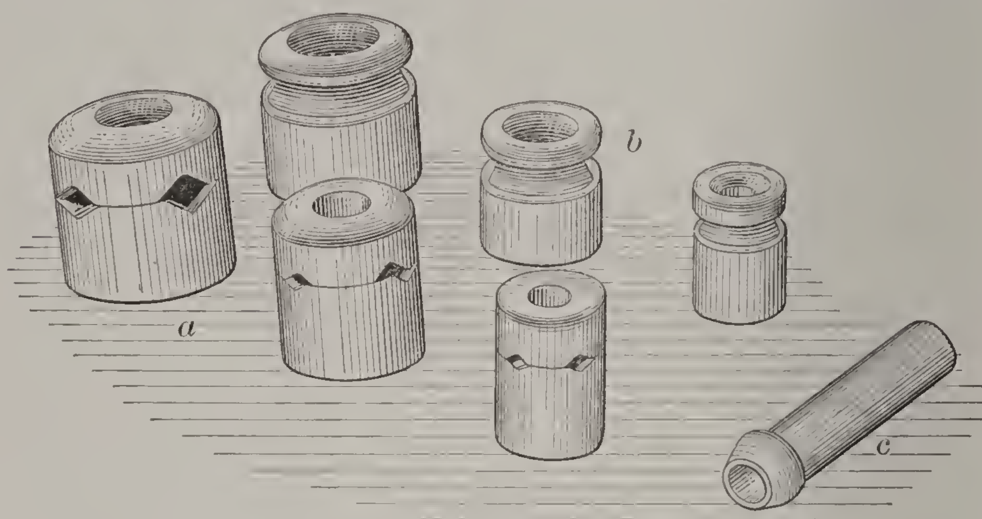


Fig. 158.—Porcelain Knobs and Tube.
a. Split knobs. *b.* Solid knobs. *c.* Tube.

(Fig. 160). These cleats are fastened by screws and grip the wires firmly when properly installed. For large wires, the best support is the single-wire cleat, provided it is heavy enough to stand the strains which occur during installation of the wire. Where only one or two circuits are to be run together the type of cleat shown in Fig. 161 is satisfactory. Table 33 gives dimensions of these cleats. Where a large number of heavy wires must be run close together, as in wire tunnels, back of switchboards and in similar places, some form of insulator rack is desirable. The style shown in Fig. 162 is useful for such work. Racks are often built from strap or angle iron to suit the requirements of the particular location. A good example of this type of construction is shown in Fig. 163.

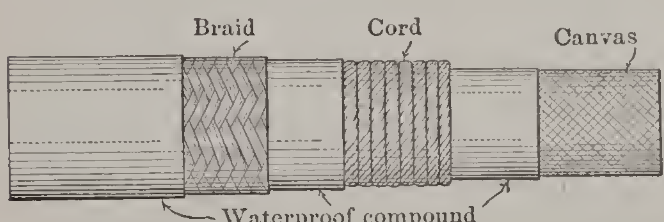


Fig. 159.—Flexible Tubing.

248. Protection of Wires. Wherever wires pass through floors or walls, they must be protected by porcelain tubes

(Rule 16*d*) (Fig. 164). For wires entering a building from an overhead line, the arrangement shown in Fig. 165 is satisfactory. Wherever the wires may come in contact with pipes or other conducting material, porcelain tubes must be placed over the wires to keep them out of contact (Fig. 166). When crossing other wires, porcelain tubes or an equivalent device must be used to separate the wires (Fig. 167). The tube should be put on the wire which is nearest the surface wired over, to keep the other wire which is not in a tube clear of this surface. Where wires are exposed to mechanical injury they must be suitably protected (Rule 26*e*). When crossing floor timbers they may be run

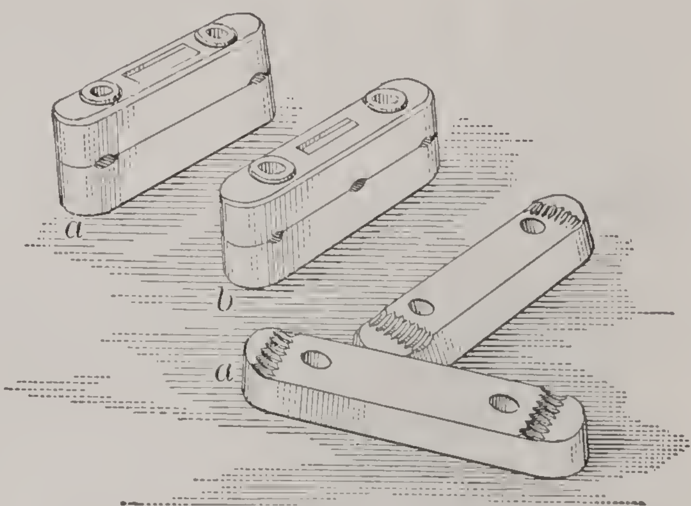


FIG. 160.—Porcelain Cleats.
a. Two-wire. *b.* Three-wire.

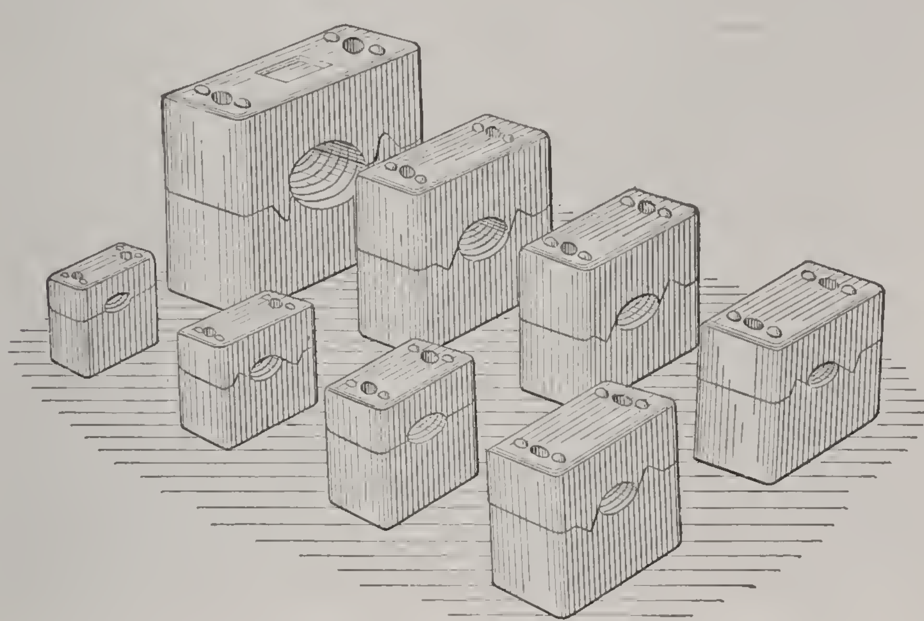


FIG. 161.—Single-wire Cleats.

on the under side of a wooden strip 3 in. wide and not less than ½ in. thick, or guard strips on either side of the wires may be used (see Fig. 168). On side walls, the protection must extend not less than 7 ft. from the floor. The wires may be enclosed in wooden boxing, closed at the top, or iron conduit may be used. Iron conduit is preferable, except in damp places (Fig. 169).

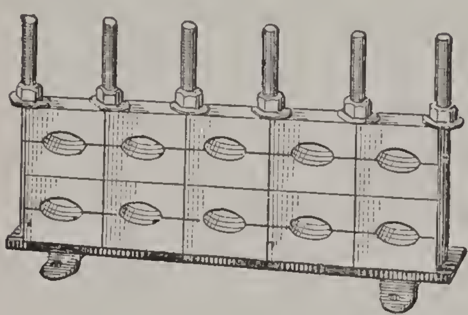


FIG. 162.—Cable Rack and Insulators.
(General Electric Co.)

249. Wire. For open wiring, rubber-covered wire (with single braid up to No. 6 gauge and double braid for larger sizes) is the best and is frequently required by local rules. The Code

FIG. 163.—Large Group of Wires on Racks.
(Factory Mutual Ins. Co.'s.)

allows the use of slow-burning insulation* under certain re-

* See paragraph 258.

strictions. For dry locations, slow-burning insulation is satis-

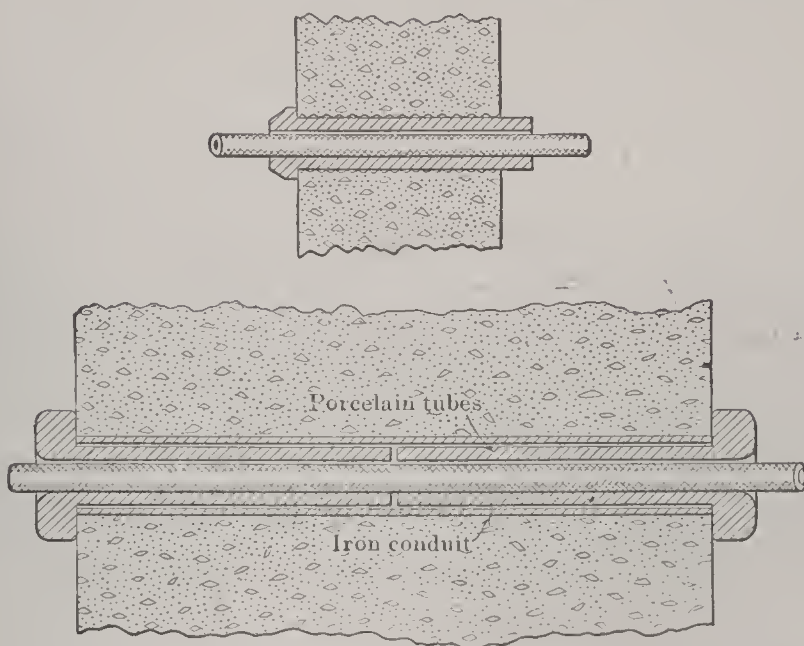


FIG. 164.—Protection of Wires Passing through Walls.
a. Thin wall. *b.* Thick wall where a single tube would be too short. The hole is bushed with a piece of iron conduit and the tubes entered at each end.

factory, and is commonly used in factories for the feeders or mains when they are run exposed, as these circuits can usually be located in places where they are not likely to be disturbed. The objection to the use of slow-burning wire is that the porcelain knobs or cleats which support the wire must be depended upon to maintain proper insulation. Where there is much moisture present there is difficulty in doing this. In damp places, therefore, rubber-insulated wire is required (Rule 26*i*). The advantages of slow-burning insulation are that it is cheaper than rubber and is not as inflammable. It has the further advantage that the smooth surface will not

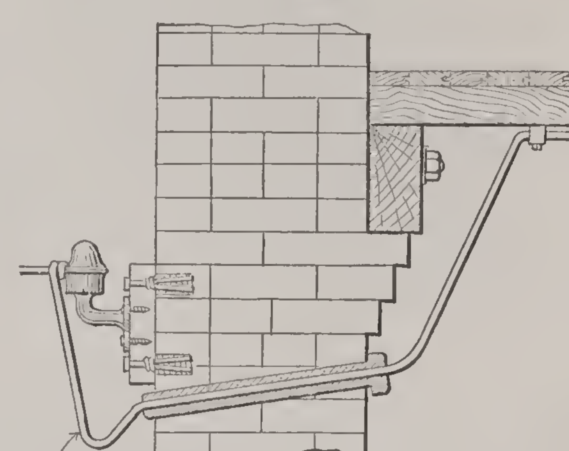


FIG. 165.—Protection of Wires Entering Building.
Wires enter through porcelain bushings. Note drip loop and bushing slanting in such a way as to exclude water. (Factory Mutual Ins. Co's.)

easily collect dust. Since the use of slow-burning wire is not always approved, it is well to consult the local inspection authorities before using it in an installation.

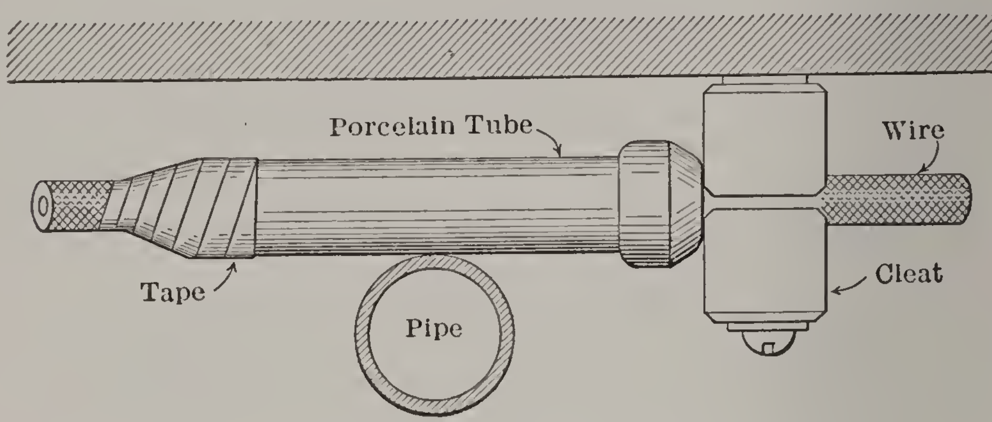


Fig. 166.—Protection of Wire Crossing a Pipe.

Tube is taped to wire to prevent it sliding along wire. When tube is not located next a cleat, each end of tube should be taped. Wire should be installed *above* the pipe where possible to prevent condensation from pipe accumulating on the wire.

250. Installation. For open work, the wires must be so supported on insulators as to give the following minimum spacings (Rule 26*h*).

Voltage.	Distance from Surface Wired Over.		Distance between Wires. Ins.
	Dry, In.	Damp, In.	
0 to 300 volts.	$\frac{1}{2}$	1	$2\frac{1}{2}$
301 to 550 volts.	1	1	4

Supports must be located not more than 4.5 ft. apart, or closer if necessary to keep the wires out of contact with surrounding surfaces. Wires which are not likely to be disturbed may be spaced 6 in. apart and run from beam to beam, even when the supports are more than 4.5 ft. apart. Smaller wires must follow the surface of the ceiling and "break around" the beams, unless they are protected by guard strips (Fig. 170). Small wires may be anchored or "dead ended" on the cleats (Fig. 171). Large wires, especially long runs, must be anchored

by strain insulators (Fig. 172). When installing supports for open wiring, particularly for large wires, care is necessary with the fastenings. On wooden surfaces or on beams, girders or trusses it is easy to obtain suitable supports for the insulator racks. When the rack must be fastened to a brick wall, an

FIG. 167.—Tap on Open Wiring.
One joint left untaped. Note position of tube where wires cross.

expansion bolt or a lead plug should be used. Wooden plugs should never be employed, as the wood is sure to dry out in time and the screw become loosened. Fig. 173 illustrates open wiring construction.

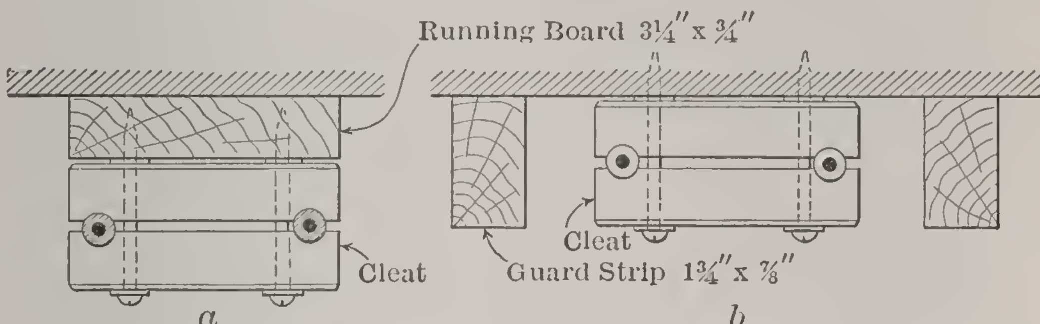


FIG. 168.—Protecting Wires from Injury.
a. Using running board. *b*. Using guard strips.

251. Comparison of Wiring Systems. As far as **mechanical protection** is concerned, the rigid conduit system is the best, with flexible conduit and armored cable nearly as good. These systems are therefore the best for use where the wires may be damaged if not suitably protected. The other systems are for use in locations where the wires will not be disturbed. As far as the **fire risk** is concerned, the rigid, flexible conduit and the

armored cable systems are equally good for moderate sizes of circuits. Rigid conduit will stand a heavier arc than will the flexible conduit or the armored cable, and consequently it is better for heavy circuits, where the arc due to a short-cir-

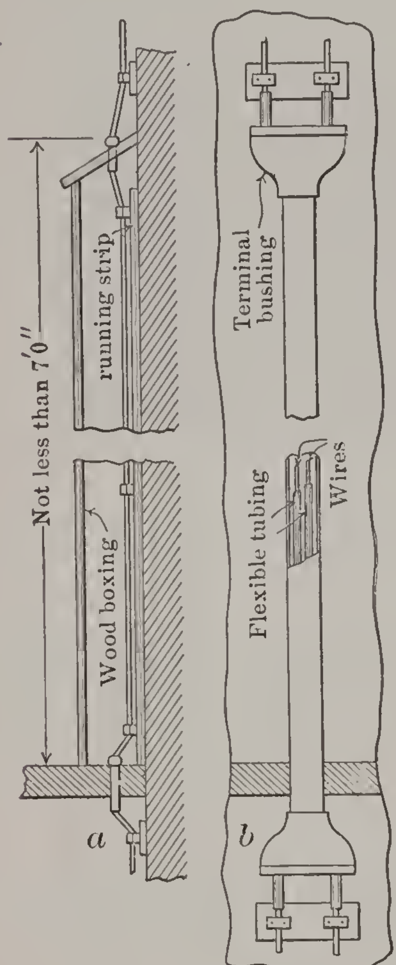


Fig. 169.—Protecting Wires on Side Walls.

a. Wooden boxing. *b*. Iron conduit protection. Flexible tubing must be used the entire distance between the cleats at either end unless rubber-covered wire is used, when it can be omitted. Bushings at ends of conduit must be used in either case.

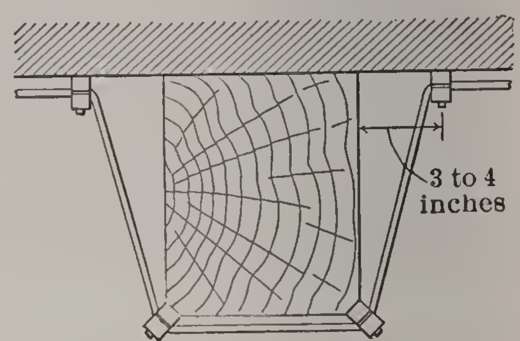


Fig. 170.—Method of Breaking around Beams.

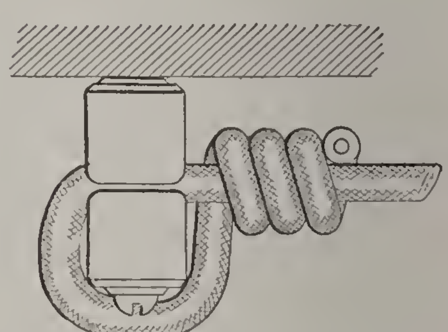


Fig. 171.—Method of Anchoring Small Wires.

Sometimes two cleats are placed side by side and the ends of the wires carried over the two and twisted as shown.

cuit might be very severe. As far as **ease of installation** is concerned, the flexible conduit or armored cable system stands ahead of the rigid conduit. This applies to concealed work, installed in either new or finished buildings. For new buildings, of course, the knob and tube system is simpler to install than

either. For exposed work, open wiring is the simplest to install. A decision as to the kind of wiring to be used is affected principally by the matter of cost. While this item is of first importance, the system which costs the least to install is not

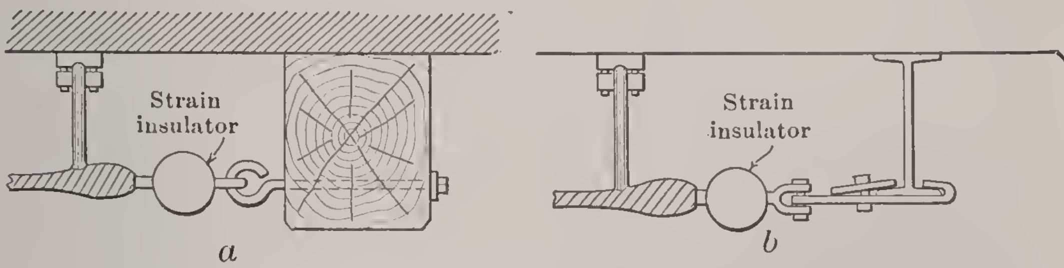


Fig. 172.—Methods of Anchoring Large Wires.

always the best or the cheapest in the end. The character of the building and the service has to be considered. If a system in a factory or an office building is so cheaply installed and of such poor construction that it is unreliable, there will be con-

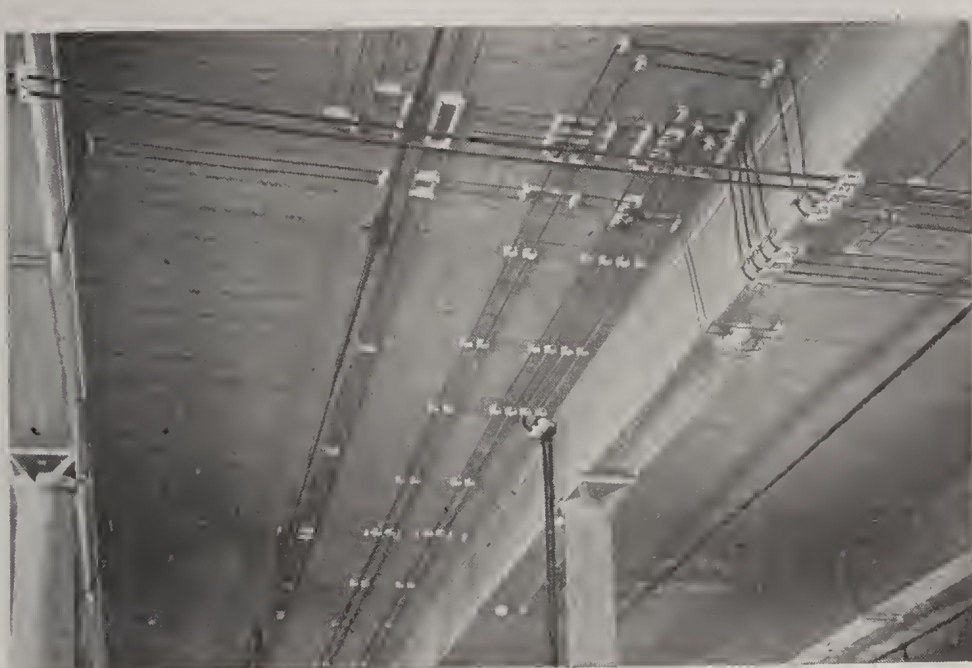


Fig. 173.—Example of Open Wiring.
(Factory Mutual Ins. Co's.)

tinual interruptions to the service. In a factory the loss caused by stopping work due to those interruptions might easily be much greater than the difference in cost between a cheap system and one which is entirely reliable. In the case of an office

building unreliable service would affect the rental value of the property. In either case, the cost of repairs and maintenance would be greater than for a better system. The relative cost of the various systems installed in new buildings is indicated below:

RELATIVE COST OF WIRING SYSTEMS

	Per Cent.
Rigid conduit, concealed	100
Rigid conduit, exposed	125
Armored cable, new work	65
Knob and tube wiring	40
Open wiring	50

This cost would vary with the type of building and would be different for work installed in old buildings. Changes in the cost of labor and material would also affect these figures.

252. Wiring of Finished Buildings. In many cases, the wiring must be installed in finished buildings where no provision was made for electric wires at the time the buildings were constructed. Such buildings include residences and very old factory or office buildings. Where the wiring must be **concealed,** as would usually be the case in residences and office buildings, either the knob and tube or the metal enclosed system (rigid or flexible conduit or armored cable) may be used. In a number of large cities, knob and tube wiring is not allowed. For metal-enclosed systems, rigid conduit is the best, but this usually requires much more cutting and removal of floors. Armored cable or flexible conduit can be fished and hence is easier to install. If either of these systems is used for damp places, however, the wire must be covered by a lead sheath. Armored cable or flexible conduit can, however, be laid in a groove in a brick wall and plastered over without requiring a lead sheath, provided the wall is not continually damp (Rule 27*d*). Frequently rigid and flexible conduit may be used in the same installation, thereby reducing the cost and obtaining a result nearly as good as an entire rigid conduit system. Such an arrangement could be used where a portion of the system is exposed to dampness. Where knob and tube wiring is allowed, this makes the cheapest system. It would be usual to remove floor boards, where required, and install the horizontal runs on

knobs. On the vertical runs, flexible tube would be used in wood partitions, and metal conduit or armored cable for brick or stone walls. **For exposed work,** the installation would be no different from those already described in previous paragraphs. Rigid conduit or armored cable is rather conspicuous, but makes the safest job. Metal moulding is fairly safe and can be made inconspicuous. Wood moulding is not very safe. It can be made in conspicuous, but its use is prohibited in some cities. Cleat or open wiring is unsightly and is exposed to damage, but it is, of course, cheap.

253. Wiring for Severe Conditions. For extremely wet places, such as canning plants, slaughter houses and breweries, special precautions must be taken with the wiring. Both open wiring and rigid conduit systems have been used. With open work, the wires are provided with a double thickness of rubber insulation and are run about 6 in. apart, supported on porcelain insulators or knobs (Fig. 174). For outlets, keyless sockets, made of moulded insulation, are preferable. The joints must be carefully made, the rubber compound being warmed and pressed firmly around the wire. The joints should then be covered with friction tape and heavily coated with insulating paint. Fuses and switches should, where possible, be placed outside the rooms and enclosed in substantial cabinets. The open system is objectionable because it is liable to be disturbed by operatives or workmen, and with the expensive wire required and the special supports it costs as much or more than a conduit system. When a rigid conduit system is used, ordinary enameled conduit can be employed if the conditions are not too severe, particularly if it is thoroughly painted after installation. Galvanized conduit is, however, more satisfactory and must be used where the atmosphere contains corrosive vapors such as exist in tank rooms, glue houses and fertilizer rooms of packing plants. Conduits for such places should be "hot galvanized." Cast-iron outlet boxes should be used and the covers should be provided with

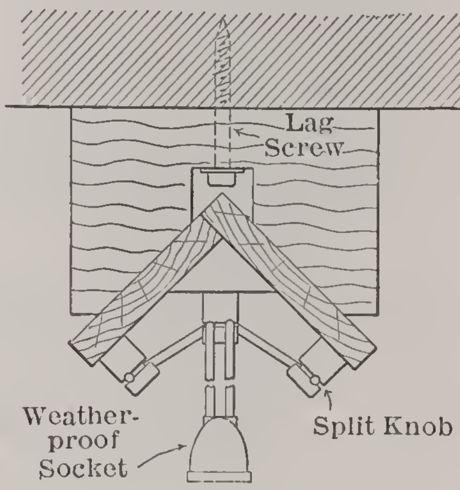


FIG. 174.—Wiring for Wet Places.

rubber gaskets. The conduit should screw into the boxes and should be made tight by means of white lead. The conduit should be repainted carefully at all joints and fittings and the entire run painted at intervals. It is also best to keep the

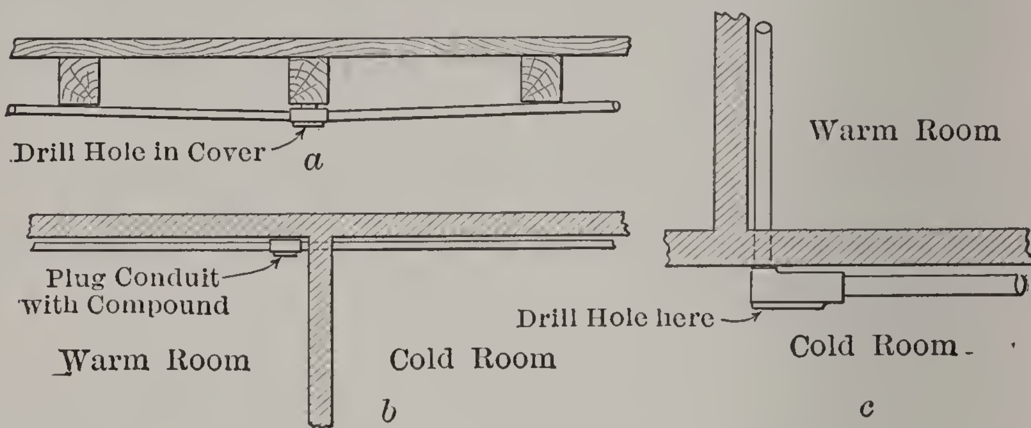


FIG. 175.—Method of Preventing Condensation.
a. Draining a horizontal run. *b.* Preventing circulation of air in conduit. *c.* Draining a vertical run.

switches and cutouts outside the rooms where the severest conditions exist. Where different parts of the conduit run are subjected to different temperatures, care must be taken to prevent water accumulating from condensation in the conduit. If cold air can circulate in the conduit system and come in contact with warmer air, the moisture in the latter will be condensed and accumulate in the conduit. The condensation can be stopped by preventing a circulation of air by plugging the conduit (Fig. 175*b*). Where steam is present or where the temperature of the room changes, the conduit can be drained into either an outlet box or cabinet, or by providing a fitting with an opening at the lowest point on the run (Figs. 175*a* and *c*). Flexible conduit with lead-covered wire has been used in some cases, but this will not withstand as severe conditions as the other systems. In all cases, it is important that the workmanship be of the highest grade. Even material of the best quality will not give satisfaction if carelessly installed. **For storage-battery rooms,** where sulphuric acid

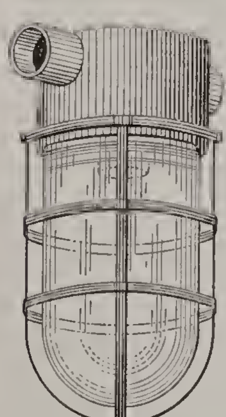


FIG. 176.—Vapor-tight Outlet.

fumes are plentiful, single conductor, lead-covered rubber insulated wire has been used successfully. Taps are made by removing the lead covering, connecting and insulating with rubber, then covering with friction tape, which is carried over the lead on each side. The tape is then painted over with insulating paint. Joints of this kind must, however, be carefully made in order to be satisfactory. In such cases the switches would be located preferably outside the room near the entrance. In rooms **where inflammable gases exist,** the lamps must be encased in a vapor-tight globe, such as is shown in Fig. 176 (Rule 31*a*). Where wiring is subject to **high temperatures** (above 120 degrees Fahr.), rubber insulation rapidly deteriorates. For such places slow-burning or asbestos insulation is required. Fixtures for large gas-filled lamps used indoors should not be wired with rubber insulated wire* (Rule 35*d*).

* See paragraphs 33 and 86.

CHAPTER 14

WIRES AND CABLES

254. Materials Used for Conductors. The metals which have been used most commonly for conductors are copper, aluminum and iron. German silver, lead and various alloys are used in electrical apparatus, such as heaters, fuses, etc., but they are never used for transmitting electricity for lighting or power service because of their high resistance. Of the three metals mentioned above, copper is most commonly used for power transmission and interior wiring because of its low resistance and relatively small cost. **Iron** is sometimes used outdoors for very long spans where copper would not be strong enough mechanically. Iron wire has a resistance from 6 to 8.25 times that of annealed copper, depending upon the quality of the material. Ordinary steel rails have a resistance of 11 to 13 times that of copper. Special steel rails which are used for third rails may have a resistance as low as 8 times that of copper. Iron or steel wire is used extensively for telephone and telegraph circuits where high resistance is not a serious disadvantage. It is never used for interior wiring, although steel rails or structural shapes are sometimes used for conducting current to cranes. **Copper-clad or bi-metallic wire** is composed of an iron or steel wire covered with a heavy coating of copper. The resistance of the wire depends upon the relative amounts of copper and iron and is expressed by the manufacturers as the per cent conductivity compared with a copper wire of the same size. Wires having respectively 30 per cent, 40 per cent and 47 per cent of the conductivity of copper are standard. This wire is chiefly used for long telephone and telegraph lines and to some extent for power transmission. It is not used for interior wiring. **Aluminum** is used rather extensively for long-distance power transmission systems where bare conductors are employed. An aluminum wire is, however, considerably larger in diameter than a copper wire having an equal resistance. Thus, if we

require a copper conductor of 1,000,000 cir. mils area, an aluminum conductor of the same resistance per foot would have to be 1,590,000 cir. mils in area. The diameter of the aluminum cable would be about $1\frac{1}{4}$ times as great as the copper wire. For equivalent sizes, the weight of aluminum wire is less than half that of copper. This is sometimes an advantage where heavy lines are used. The cost of bare aluminum wire for the same resistance is about the same as for copper. Insulated aluminum wires would, therefore, cost more and would require larger conduits than copper wires. It is also very difficult to solder aluminum. These disadvantages prevent the general use of aluminum for interior wiring. The following discussion of insulated wires will, therefore, be confined to **copper conductors**. The copper used for electrical purposes must be very pure. Even slight amounts of different metals or other impurities greatly increase the resistance. Nearly all the copper used for electrical conductors is refined electrically. In one of the methods used, the crude copper is cast into the form of heavy plates which are hung in a tank containing a solution of copper sulphate (blue vitriol) and other substances. These plates are connected to the positive terminal of an electric circuit, the negative terminal being connected to thin plates of pure copper which are hung close to the crude copper plates. The copper is deposited on the negative plates by the action of the current and the impurities in the crude copper drop to the bottom of the tank. The pure copper plates are then removed from the tanks, melted in a furnace and cast into bars about 4 in. square. These bars are rolled, while hot, until the cross-section is reduced to a rod about $\frac{1}{4}$ in. in diameter. After cooling, the rod is cleaned from scale and is then drawn through a tapering hole in a steel plate. There is a limit to the reduction which can be made by passing through the steel plate or "die," so that for fine wires the drawing process must be repeated a large number of times. The drawing tends to harden the wire and to increase its tensile strength and stiffness. After a certain amount of drawing has taken place the wire becomes too hard and must be "annealed" by heating in a furnace. This makes the wire "soft" again. **Hard-drawn and medium hard-drawn copper wires** are produced by proper wire drawing and are not annealed after the drawing process is completed. These wires are stronger and more elastic than

annealed wire and are, therefore, used chiefly for outdoor purposes where mechanical strength is necessary. The principal applications are for trolley wire, transmission lines, telephone and telegraph lines. The resistance is about 2.7 per cent greater than for soft copper. **Annealed or soft copper wire** is produced by carefully annealing after the drawing process is completed. The wire can be easily bent, but is only about 60 per cent as strong as hard-drawn wire. It is used for the windings of electrical machinery and for insulated wires used for interior wiring.

255. Wire Gauges. Copper wires in the smaller sizes (up to about $\frac{7}{16}$ in. diameter), are measured by the Brown & Sharpe (B. & S.), or American Wire Gauge (A. W. G.). The sizes run from No. 40, which is 0.0031 in. in diameter, to No. 0000, which is 0.460 in. in diameter. Larger sizes are designated in **circular mils,** the usual sizes running from 250,000 cir. mils, which is slightly larger than No. 0000, to 2,000,000 cir. mils which is 1.631 in. in diameter. The sizes usually made advance by 50,000 cir. mils up to 1,000,000 and by 100,000 cir. mils from this size to 2,000,000. In the B. & S. gauge, the wires double in cross-section for every three sizes. Thus, a No. 7 wire is exactly twice the area of a No. 10 wire. A No. 4 wire is twice the area of a No. 7 wire, etc. A No. 4 wire will not, however, carry twice the current that is safe for a No. 7 wire (see Table 36). The diameters of round wires are sometimes expressed in **mils.** A mil is one thousandth of an inch. Thus a No. 10 wire is 0.102 in. or 102 mils in diameter. The areas of wires are frequently expressed in **circular mils.** A circular mil is the area of a circle one mil or 0.001 in. in diameter. The area of any round wire expressed in circular mils is found by squaring the diameter of the wire, measured in mils. Thus, a No. 10 wire has a diameter of 102 mils, and, therefore, the area is: $102 \times 102 = 10{,}404$ cir. mils, or 0.00816 sq.in.

Rectangular areas are sometimes measured in square mils. This is found by multiplying together the dimensions measured in mils. Thus a bar 3 in. by $\frac{1}{4}$ in. measures 3000 mils by 250 mils. The area is, therefore, $3000 \times 250 = 750{,}000$ square mils, or 0.75 sq.in. Sometimes it is desired to find the number of circular mils in a rectangular section. To change from one system to the other, we have,

circular mils = square mils $\times$ 1.273;
square mils = circular mils $\times$ 0.7854;
circular mils = square inches $\times$ 1,273,000;
square inches = circular mils $\times$ 0.0000007854;
square inches = square mils $\times$ 0.000001;
square mils = square inches $\times$ 1,000,000.

For the copper bar, therefore, the area is $750{,}000 \times 1.273 = 955{,}000$ cir. mils. The area of a wire is of importance, since the resistance decreases exactly as the area increases. Thus a 1,000,000 cir. mil cable is one-half the resistance per 1000 ft. of a 500,000 cir. mil cable, and a 2,000,000 cir. mil cable is one-quarter the resistance of the 500,000 cir. mil cable. The B. & S. gauge sizes and the corresponding area in circular mils are given in Table 36. In finding the resistance of a conductor the resistance of a wire one mil in diameter and one foot long is used as a standard. This is called a mil-foot. The value of the resistance per mil-foot for commercial copper wire at 75° Fahr. is 10.75 ohms. The resistance of a wire can be calculated from the formula:

$$\text{Resistance} = \frac{10.75 \times \text{length in feet}}{\text{cir. mils.}}. \tag{1}$$

Example 1. Find the resistance of a wire having a cross-section of 16,500 c.m. and 1500 ft. long.

$$\text{Resistance} = \frac{10.75 \times 1500}{16{,}500}$$
$$= 0.978 \text{ ohm.}$$

The size of wire for a given resistance is found by the formula:

$$\text{Cir. mils} = \frac{10.75 \times \text{length in feet}}{\text{Resistance in ohms}}. \tag{2}$$

Example 2. Find the size of wire to have a resistance of 0.2 ohm when the length is 2000 ft.

$$\text{C.m.} = \frac{10.75 \times 20{,}000}{0.2}$$
$$= 107{,}500 \text{ c.m}$$

Example 3. Find the resistance of a rectangular bar 3 ins. by $\frac{1}{4}$ in. and 20 ft. long. From previous calculations, the size was found to be 955,000 c.m. Hence the resistance is:

$$\text{Resistance} = \frac{10.75 \times 20}{955{,}000}$$
$$= 0.000225 \text{ ohm.}$$

256. Solid and Stranded Conductors. Solid conductors are composed of a single wire. Sometimes this is called a **solid wire** or simply a wire. Stranded conductors are composed of a number of wires twisted together. This is generally called a **cable.** A very small stranded conductor is usually known as a **stranded wire. Twin wire or duplex wire** consists of two separately insulated wires, laid parallel and having an outside braid which encloses both wires. For interior wiring, where the conductor is installed in conduit, it is usual to employ stranded wires or cables in sizes No. 8 and larger, as it is difficult to pull large solid wires into conduit. Where the wires are run open, there is not this objection to the use of solid wires, but in this case it is advisable to use stranded wires in sizes above

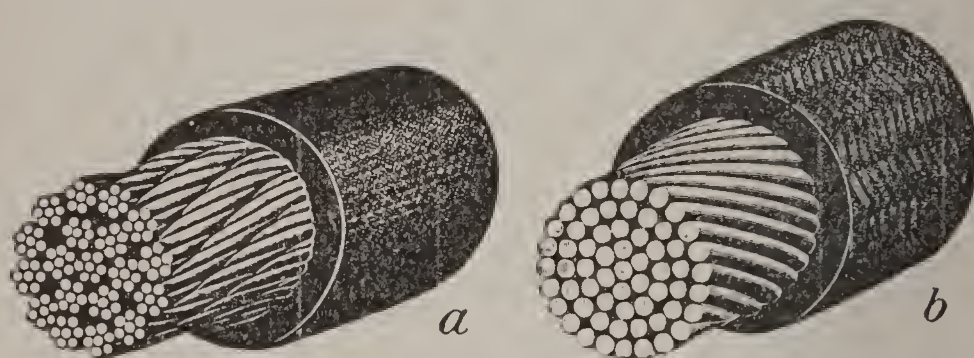


FIG. 177.—Cables.
a. Rope stranding. *b.* Concentric stranding.

No. 1 because of the difficulty of taking the kinks out of a heavier solid wire so as to give a good appearance. Cables are almost always used for sizes larger than No. 0000. Cables are slightly more expensive than solid wires. There are two kinds of cables in use. For **rope-laid cables** (Fig. 177*a*), the wires are first twisted together in groups of sevens, and these sevens are then combined to make up the cable. This arrangement makes a more flexible cable than the other type, but the diameter is greater for a given cross-section of copper. It is used principally for making very large, extra-flexible cables. **The concentric-laid cable** uses a number of wires all of the same size, laid up in layers around one central wire (Fig. 177*b*). This is the common type of cable used for electrical conductors. Cables can be made up of different numbers of wires, the smaller the wires, the greater the flexibility of the cable. The cost, however, is greater for a large number of fine wires. The stand-

ard strandings adopted by the manufacturers are chosen so as to give sufficient flexibility for all wiring purposes, except portable or machine cables. In Table 34 is given the strandings generally used. With the help of this table, the size of a stranded wire can be easily determined by measuring the diameter of one wire and counting the number of wires or strands. The values given in heavy type are the ones most commonly used. It will be seen from this table that the size of wires used for ordinary cables varies from about No. 16 for small-size cables to No. 8 for larger sizes. The number of strands is never less than seven. For extra-flexible wires, such as lamp cord, smaller individual wires are used. Thus, ordinary No. 18 lamp cord is composed of sixteen No. 30 gauge wires. Extra-flexible cables such as are used for dynamo leads are composed of a large number of fine wires and are sometimes rope laid.

Insulated Conductors

257. Rubber Insulation. The rubber insulation used on wires and cables is composed of from 20 to 40 per cent of India rubber, the remainder being usually mineral matter of various kinds, such as talc, zinc oxide, red lead, etc., with a small amount of sulphur. Pure rubber cannot be used for wire insulation because it will not stand high temperatures and is too soft to withstand the rough usage to which wire is subjected. The rubber, after being washed, is "compounded" or mixed with the mineral matter by working through heated rolls, until it is thoroughly plastic. The compound is then rolled out into thin sheets and cut into strips suitable for applying to the wire. Copper wire which is to be covered with rubber insulation is always thoroughly tinned to protect the copper from the corroding action of the sulphur in the compound. For small wires the compound is applied by pressing it through a die, at the centre of which the wire is located. Large wires usually have the insulation applied in the form of a strip which is carried along parallel to the wire and is folded over and compressed tightly around it by means of grooved rollers. After the insulation is applied, it is vulcanized by heating to the proper temperature. This is usually done by placing the coils of wire in large, closed drums and admitting live steam at a pressure of about 25 pounds. This process causes the sulphur to com-

bine chemically with the rubber, with the result that it is no longer plastic but firm, elastic, strong, and less affected by heat or cold or the action of the air. After the insulation has been vulcanized, the wire is covered by one or two cotton braids, which are thoroughly filled with a weatherproof compound.

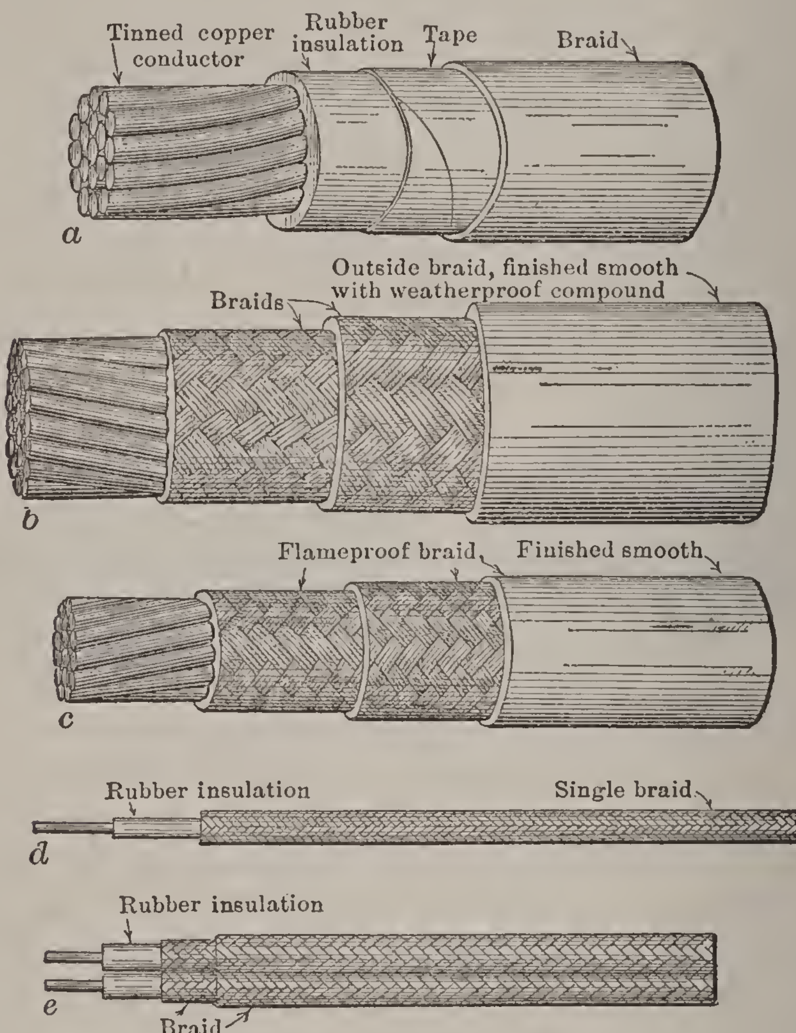


FIG. 178.—Insulated Wires and Cables.

a. Rubber-covered cable. *b.* Triple braid weatherproof cable. *c.* Slow-burning cable. Slow-burning weatherproof cable is similar except that the inner braid is weatherproof. *d.* Fixture wire. *e.* Duplex wire.

Sometimes, on large wires, a tape is used instead of the inside braid (Fig. 178). The character of the rubber insulation depends to a considerable extent upon the quality of rubber used and also upon the percentage of rubber in the compound. For many years, the best rubber has been obtained from Brazil, the brand called "Para" being the most satisfactory. African rubbers are in general inferior in quality. Insulation manu-

factured to meet the Code rules requires about 20 per cent of rubber, but it does not need to be of the highest grade. A compound containing 30 per cent Para rubber is made by a number of manufacturers. This insulation is much superior to the Code insulation and is used for important work and for high-voltage installations. A grade of insulation intermediate between Code insulation and 30 per cent Para insulation is also manufactured. This is much better than the Code insulation and is used in many high-class installations where freedom from breakdowns is important. No rubber insulation poorer than that required by the Code should ever be used for electric light and power wiring. **Tests of rubber insulation** are made by the manufacturers and sometimes by the purchaser. The principal tests are a high-voltage test followed by a test of the insulation resistance. Both of these are made while the wire is immersed in a tank of water. Samples of the insulation are also stretched under specified conditions. The dimensions of the standard Code wire for voltages up to 600 volts are given in Table 35. **Fixture wire** is insulated with a wall of rubber thinner than that on the regular wire. Nothing smaller than No. 18 wire is allowed, and No. 16 is preferable where it is possible to use it. As a rule, solid wire is used, but stranded fixture wire can be obtained. The wire is covered with a single braid. Fixture wire (Fig. 178*d*) is considerably smaller than the regular No. 14 wire, which is the smallest size allowed outside of fixtures. Every length of Code wire has attached to it a label of the inspection department of the Fire Underwriters, certifying that the wire has been made in accordance with the rules laid do wnin the Code. Rubber-insulated wire must be used in all conduit systems, in wood or metal moulding and in knob and tube work. It is also frequently used for open work and is sometimes required by local rules. For damp places, rubber-insulated wire must be used. If rubber insulation is continually exposed to very high temperatures, it deteriorates and becomes brittle. To ensure a long life, it has been found that the temperature should not exceed 150° Fahr. for any considerable length of time.

258. Weatherproof Insulation. Weatherproof wire (Fig. 178–*b*), has an insulation consisting of three braids of fibrous yarn placed over the copper conductor, which is not tinned. During the process of manufacture the braids are thoroughly saturated with a waterproof compound. This wire is used

chiefly for outdoor service (Rule 12), and is not allowed for interior wiring except where corrosive vapors exist (Rule 26*i*). The advantages of this insulation are that it is cheap and durable except when exposed to high temperatures. The disadvantage is that it is very inflammable. **Slow-burning weatherproof wire** is not as inflammable as weatherproof wire. The insulation consists of an inner braided covering which is weatherproof and an outer braided covering which is flameproof (Rule 55). This wire is not really fireproof, as the inside covering will burn if subjected to enough heat. The outside covering is filled with a flameproof paint, which will not easily carry a flame along the wire. Slow-burning weatherproof wire is allowed by the Code for use in open wiring in dry places (Rule 26*g*), but it is not commonly used. **Slow-burning wire** (Fig. 178*c*), has three braids, all of which are filled with a flameproof paint. This wire is somewhat like the old "Underwriters'" wire (Rule 56). It is the wire most commonly used for open work in dry places, especially in factories. Fixture wire having slow-burning insulation is required where temperatures above 120° Fahr. exist, as in some designs of show-case fixtures (Rule 30*c*), and for indoor fixtures for large gas-filled incandescent lamps (Rule 35*d*). None of the three kinds of insulation just mentioned are nearly so good as rubber as an insulator. In fact, when weatherproof or slow-burning wire is used, the porcelain supports are depended upon to properly insulate the wires. For this reason, these insulations cannot be used satisfactorily in damp places. The covering on the wire can be depended upon only to prevent a short-circuit between wires and to reduce the danger of receiving a shock. All three kinds of wire are cheaper than rubber insulated wire. They are sold by the pound, whereas rubber wire is sold by the foot.

259. Other Insulations. Conductors are sometimes insulated with **paper** impregnated with an insulating oil. Paper insulated cables must always be enclosed in a lead sheath to keep out moisture. They are used principally for high-voltage work in underground systems and are not recognized by the Code for ordinary low-voltage interior wiring. **Varnished-cambric** insulated cables have been used to some extent for interior wiring. This insulation consists of spirally wrapped layers of cotton tape which has been treated with an insulating varnish. In the process of wrapping, the layers are coated with

a thick insulating compound to fill the spaces. Cable of this type is made with two braids similar to rubber cables. When so constructed it will withstand immersion in water and can be tested in the same manner as rubber insulation. It is not suitable, however, for installation where it is permanently exposed to moisture, as the filling compound will gradually work out and the insulation be destroyed. There is also some tendency for the cable to dry out when exposed to a warm atmosphere. The cost of such a braid-covered cable is less than rubber insulation, but varnished-cambric cable is not yet recognized by the Code for general use in interior wiring. It is used extensively, however, in power stations, especially for high-voltage wiring. By the addition of a lead sheath, the varnished-cambric cable can be used in wet places and so constructed is used to a considerable extent for underground systems in place of paper or rubber insulation. It costs less than rubber and more than paper insulation.

260. Multiple Conductors. Frequently two or more wires are combined in one braid or lead sheath to form a multiple cable. **Duplex or twin wires** (Fig. 178*e*), consist of two rubber-insulated and single-braided conductors, laid parallel and covered with a common braid. Wires of this kind occupy slightly less space than two single wires and also cost less. They are, therefore, very commonly used for branch circuits in lighting service. **Triplex or three-conductor cables** have three separately insulated conductors enclosed in a common braid. These cables are used for small three-wire circuits and sometimes for three-phase work. **Flexible cords** (Rule 51) consist usually of two separately insulated, extra flexible, stranded wires. The wires which make up the strand are very small, generally about No. 30. Rubber insulation is placed on each wire and sometimes another layer of rubber is placed over the conductors after they have been twisted together. Ordinary **lamp cord** has a cotton braid placed over the rubber insulation on each conductor. The two conductors are then twisted together (Fig. 179*a*). Lamp cord is allowed for use as a pendant or drop-fixture in dry places (Rule 32). **Canvasite and brewery cords** (Fig. 179*b*) have a weatherproof braid around each conductor and a second weatherproof braid around the two conductors after they have been twisted together. These cords are for use as pendants in damp places. **Reinforced cord** (Fig. 179*c*) is

twisted lamp cord covered with a rubber jacket enclosing both conductors. A single cotton braid covers this rubber jacket. This cord is used for portables in dry places where not subjected to rough usage as in offices, dwellings, etc. (Rule 51*f*). For damp places, the outer braid is weatherproof (**Reinforced cord, weatherproof**) or two weatherproof braids are used (**Packing-house cord**). **Armored cords** have a flexible, galvanized steel armor similar to that used on the regular armored cable described in paragraph 238. The cord which is armored may be either regular lamp cord, or reinforced cord for dry places, or

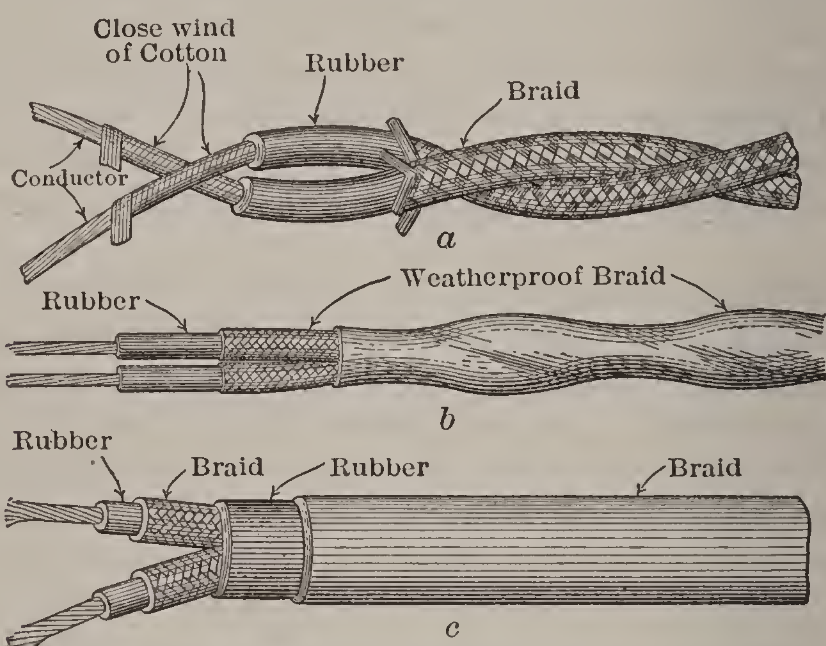


FIG. 179.—Flexible Cords.
a. Lamp cord. *b*. Canvasite cord. *c*. Reinforced cord.

weatherproof reinforced cord for damp places. Armored cords are used chiefly for portables subjected to rough usage, as in show windows.

261. Carrying Capacity of Conductors. The current which insulated conductors will stand is limited to an amount which will not overheat the wires and damage the insulation. Rubber insulation will not withstand as high a temperature as weatherproof insulation without deteriorating and, hence, a lower current rating is used for rubber wire. Table 36 gives the maximum current allowed by the Code for both types of insulation. The Code makes no distinction in carrying capacity of wires when used for alternating or direct current. For alternating currents, par-

ticularly at 60 cycles, the apparent resistance is increased due to the skin effect.* This would cause the wires to run somewhat hotter than when carrying direct current. According to the rules of the Code, the rating of the fuse protecting a wire must not be greater than the safe carrying capacity as given in

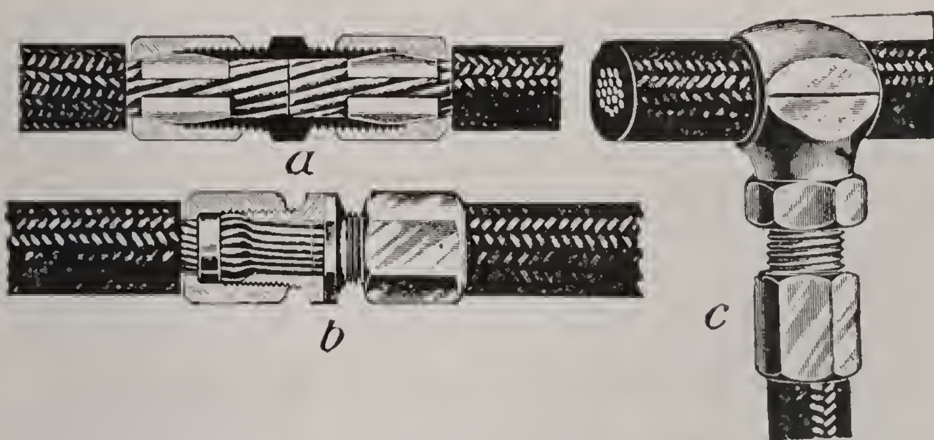


FIG. 180.—Cable Connectors. (Dossert.)
a. Two-way connector, type A for light mechanical strains. *b*. Two-way connector, type B for heavy mechanical strains. *c*. Cable tap.

Table 36. This makes it possible to carry a small overload on the wires, since enclosed fuses will carry 10 per cent excess current and open fuses about 25 per cent excess, without opening the circuits. Table 36 gives the maximum current which wires can carry, but in many cases the current carried must be made considerably less than the values given, to prevent excessive voltage drop.† This matter is fully treated in Chapter 19.

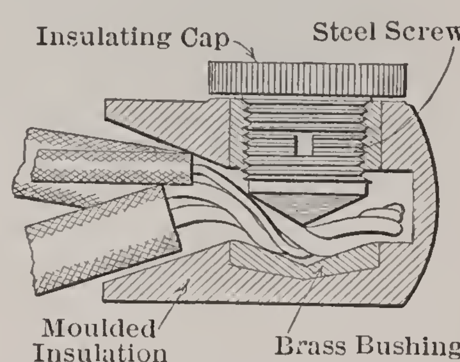


FIG. 181.—Fixture Wire Connector. (USEM).

262. Splicing Wires and Cables. The Code requires that all taps and splices be made mechanically secure and then soldered (Rule 16c). An exception to this is made where an approved connector is used. The common types of one make are shown in Fig. 180. There are several approved connectors for splicing fixture wire, one of which is shown in Fig. 181. Stranded wires may be spliced as shown in Fig. 182. A somewhat simpler

* Paragraph 323. † Paragraph 320.

form of splice can be used where the wires are not subjected to mechanical strains. Splices must be thoroughly soldered, using a non-corrosive soldering paste or fluid. So-called "acid" (muriatic acid "cut" with zinc) should not be used on electrical work. When rubber-covered wires are spliced, the soldered

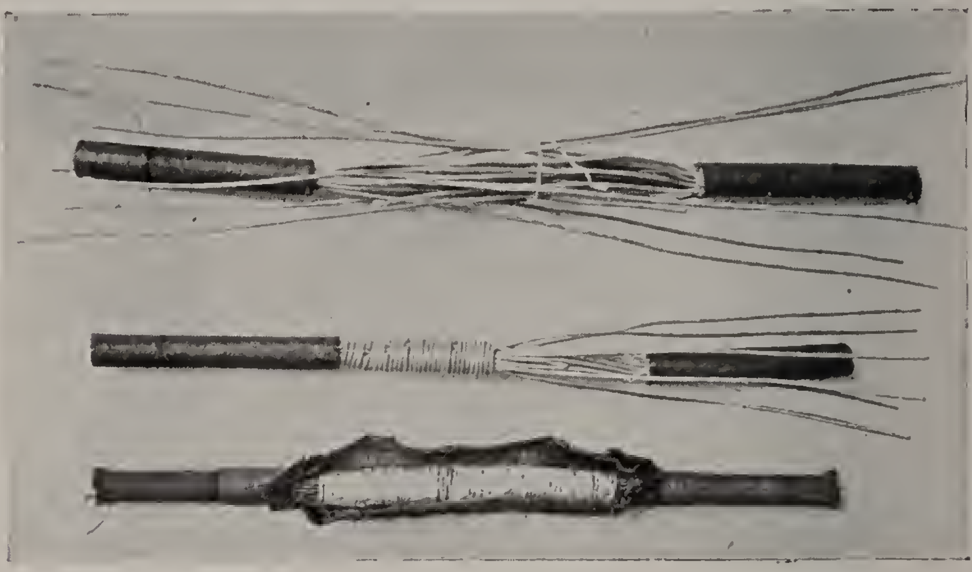


Fig. 182.—Method of Splicing a Cable.

The upper illustration shows strands laid out straight and centre core cut away. The next illustration shows half the remaining strands wrapped around the cable. The lower illustration shows the splice soldered and taped.

connection must be covered with rubber compound tape to a thickness equal to the insulation on the wire and then covered with friction tape. Splices in weatherproof wires are covered with friction tape only.

CHAPTER 15

SWITCHES, CIRCUIT BREAKERS AND FUSES

Knife Switches

263. Construction. Knife switches consist of a blade hinged at one end and arranged to enter a forked terminal or jaw at the other. The general arrangement of knife switches of various sizes is shown in Figs. 183, 184 and 185. **The blade** is made of

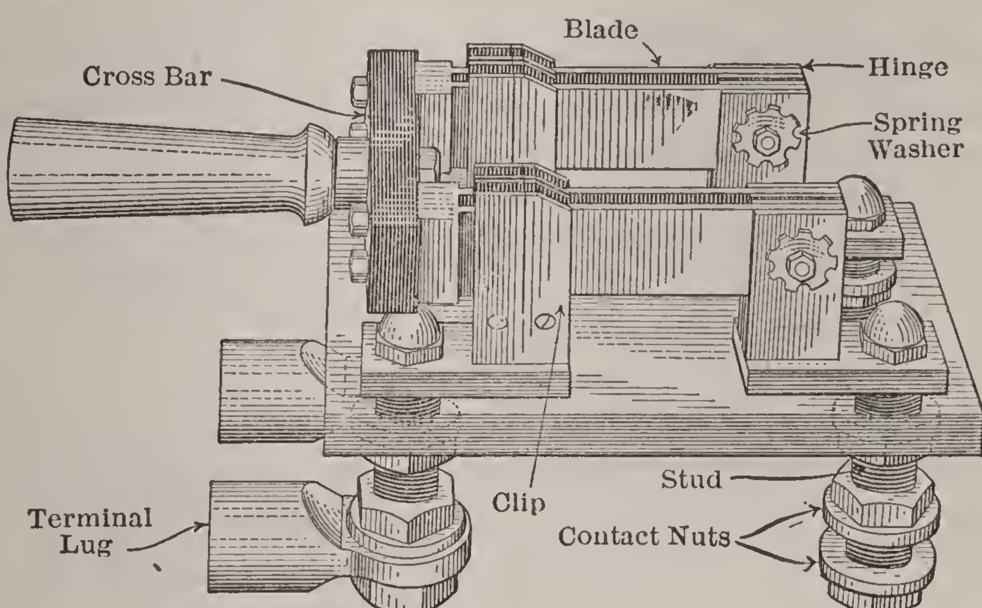


Fig. 183.—Knife Switch. Back connected, double pole, single throw, 800 amperes, 250 volts.

one or more copper bars, the cross-section depending upon the rated capacity of the switch. Large-capacity switches have multiple blades (Fig. 183). **The clip and hinge** are made somewhat similar and are composed of hard-rolled copper so that they will make good spring contact with the blade. At the hinge end, **spring washers** are used to secure proper contact. The switch must be mounted on an insulating base which may be a switchboard panel or an individual slab. For

very small switches porcelain bases are used. For larger switches, usually above 30 amperes, slate or marble bases are generally used because porcelain in large slabs is difficult to make and is not strong mechanically. Switches for voltages higher than 3300 volts are generally mounted on porcelain insulators. The Code (Rule 65) specifies the general construction of all knife switches, as regards size of parts, spacing, etc. **The connections** to the switch may be either on the front or back, the kind used depending upon the service intended. In **back-connected switches** (Fig. 183), the hinge and clip are connected to threaded copper studs which project through the base sufficiently to provide space for the connections. Switches for currents larger than 30 amperes must be provided with terminal **lugs** into which the wires are soldered (Rule 65*h*). These lugs are clamped between nuts on the threaded studs. In some cases, instead of the studs, flat bars are used. The flat copper connections are bolted directly to these bars. **Front-connected switches** have an extension on each hinge and clip, arranged for connecting to the wires, with terminal lugs where required (Fig. 184). Switches of more than one pole (two-pole, three-pole, etc.) are built from single-pole switches by connecting the blades to an insulating cross-bar to which the handle is attached. Switches are made **two-throw** by providing a set of clips on either side of the hinge. Knife switches are made in sizes from 30 to 10,000 amperes or more. Fig. 185 shows a type of switch used in branch circuits for lighting panel boards. The Code requires that the **rating** of a switch be stamped on the blade. This includes the maximum current and the voltage. This does not necessarily mean that the switch will open this

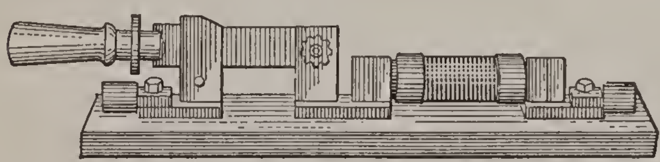


Fig. 184.—Front-connected Knife Switch. Single pole, single throw, fused, 100 amperes, 250 volts.

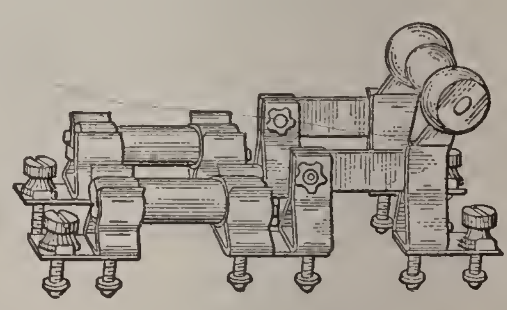


Fig. 185.—Fused Knife Switch for Lighting Panel Boards.

current when used on a circuit of the rated voltage. The voltage rating simply means that the break distance, that is the distance between nearest points on the blade and clip of the same pole, and the spacing between poles, is in accordance with the values given in the Code (Rule 65*k*). With large capacity switches, particularly for 600 volts, it would not be safe to open heavy currents by means of an ordinary knife switch. Instead, either a circuit breaker or a quick-break switch must be used.

264. Quick-break Switches are provided with an auxiliary blade which is independent of the handle (Fig. 186). When the main blade is first moved out of the clip, this auxiliary blade remains in the clip and keeps the circuit closed. Further motion of the main blade puts a tension on springs which connect the two parts of the blade. Finally a stop at the hinge end of the auxiliary blade prevents any further extension of the springs, and the blade is pulled out of the clip. The springs then give the blade a quick motion, thus breaking the circuit rapidly and reducing the arcing. Quick-break switches are used for the field circuits of a.c. generators and for breaking large currents at 250 volts and above. Quick-break switches must be used for switches designed for currents greater than 100 amperes at voltages higher than 250 (Rule 65*k*).

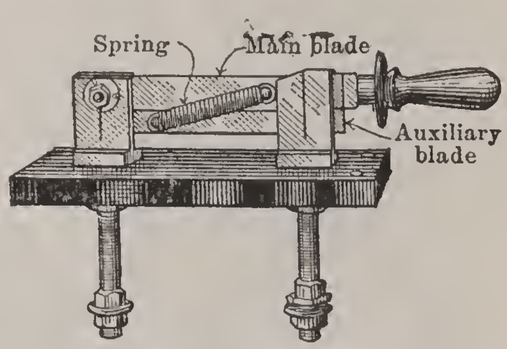


FIG. 186.—Quick-break Knife Switch.

265. Applications. For all circuits larger than about 20 amperes' capacity, knife switches (or sometimes circuit breakers) are used for the purpose of disconnecting a circuit or for transferring it from one supply to another. On switchboards they are used for disconnecting generators and feeders. When the supply of electricity is from a central station, a **service switch** and fuse-cutout are always provided (Rule 24*a*). Switches are also used on panel boards for disconnecting branch circuits and for individual motor circuits, to entirely disconnect the motor and control apparatus from the line. **Single-pole switches** are allowed only in special cases. Usually the switch must disconnect all wires of a circuit (Rule 24*c*). Single-throw switches

are placed handle up so that gravity will tend to open the switch. Wherever possible, the line side of the circuit is wired to the top terminals of the switch, so that the blades will be "dead" when the switch is open. Double-throw switches may be mounted horizontally or vertically. If mounted vertically, a stop must be provided to prevent the switch blades falling into the lower clips. Knife switches are used for all d.c. voltages. For alternating current they are commonly used up to 600 volts and in special cases for higher voltages. Oil switches are better for alternating current circuits above 250 volts.*

Rotary Snap Switches

266. Construction. Snap switches are used for controlling small currents. They consist of pivoted insulated blades which make contact with the terminals to which the circuit wires are attached. The blades are moved by means of a handle, through a spring and cam motion, which does not allow the blades to move until the handle has been twisted nearly a quarter turn. When this is done, the blades are released and are given a quick motion to open or close the switch. The ordinary form of snap switch for mounting on the surface of a wall is shown in Fig. 187. The switches are also mounted in an enclosing porcelain base and are then used for concealed work, with only the handle projecting. Such switches are called **rotary flush switches** (Fig. 188). Switches are made both single- and double-pole in capacities of 5, 10, 20 and 30 amperes. The two larger sizes are not used as much as the others. The ordinary switches are not designed for more than 250 volts, although special switches for 500 volts may be obtained.

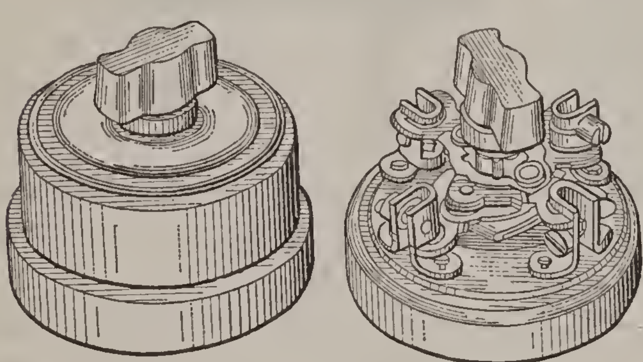


Fig. 187.—Rotary Snap Switch. (Double pole.)

267. Special Snap Switches. Besides the ordinary single- or double-pole switches which are used to open one or both lines

* See paragraph 276.

of a two-wire circuit, there are a number of special snap switches in common use. These are the same size as the regular switches, the difference being in the arrangement of the parts. **Three-way switches** have three terminals and are arranged so that the switch blade always makes contact with one or the other of two of the terminals. They are used to control lamps from two points as shown in Fig. 225. Since these switches control only one side of the circuit, they must be considered as single pole. When lamps are to be controlled from more than two points, a **four-way switch** must be used at the intermediate points (Fig. 225). These switches have four terminals and two switch blades. The terminals are connected together in different ways for each motion of the handle. **Two-point electrolier switches** have three terminals and a single blade. They are used to light either or both groups of lamps or to extinguish them all. **Three-point electrolier switches** have four terminals and a single blade. They are used to control lights in three sections. Electrolier switches are used for large fixtures or "electroliers" to give control of the lamps in groups.

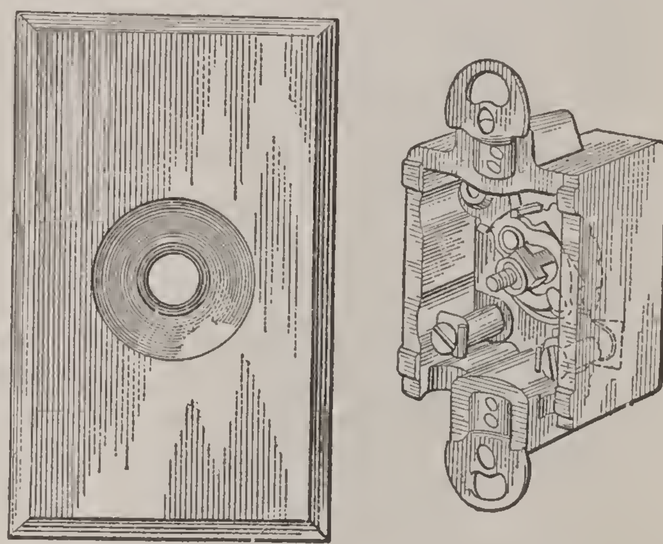

a *b*

FIG. 188.—Rotary Flush Switch. (Single pole.)

a. Switch plate. *b.* Switch with plate and operating handle removed.

268. Switch Fittings. Surface switches, when used with exposed wiring, are supported away from the wall either by porcelain knobs or by porcelain switch blocks or sub-bases which have grooves for the entrance of the wires to the base of the switch (Fig. 189). For moulding or concealed work, similar porcelain bases are used. When flush switches are used, they must be enclosed in a metal outlet box, whether they are used with conduit systems or not (Rule 24*d*). Usually regular steel outlet boxes are employed, with a cover having a rectangular

opening to fit the switch (Fig. 122*c*). For flush switches, metal **switch plates** (Fig. 188*a*), are used to cover the mechanism and the outlet box. These are about $\frac{1}{8}$ in. thick and are finished to match the hardware in the room.

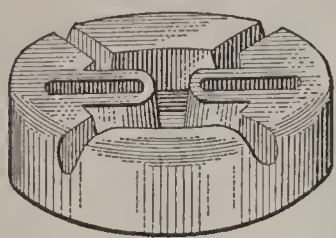


Fig. 189.—Porcelain Switch Base.

269. Applications. Snap switches are generally used for controlling branch lighting circuits and small motors. They are preferable to knife switches for circuits up to 20 amperes and 250 volts because they give greater protection to the user and can be installed in places where knife switches would not be suitable. The rules under which single- and double-pole switches are installed are given in paragraph 301. Double-pole switches cost about 30 per cent more than single-pole. Surface switches are used with open or moulding wiring, and also in cheap installations of knob and tube wiring. For concealed work, the flush type switch is sometimes used, but more commonly a push-button switch is employed.

Push-button Switches

270. Construction. Push-button switches are used only for small currents. They contain one or more contact blades which are given a rocking motion by the buttons, instead of the rotary motion as in snap switches. By means of a spring and cam mechanism similar to that on the rotary snap switches, the blades make contact with clips or jaws attached to the terminals. The blades, therefore, open and close with a quick motion, which assists in extinguishing the arc. Push-button switches are arranged in a porcelain block which encloses the live contacts. They are intended principally for flush mounting (Fig. 190). Switches are made in 5- and 10-ampere sizes and for voltages up to 250 volts. **Special switches,** such as three-way and four-way,

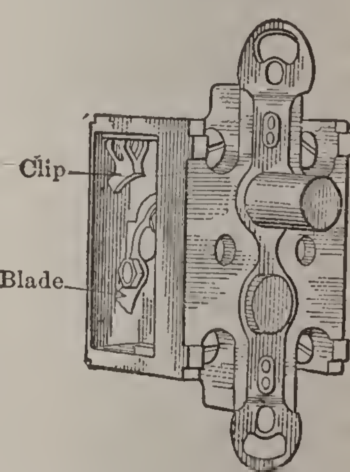


Fig. 190.—Push-button Switch. With portion of porcelain cut away to show mechanism. (Double pole.)

are also made. The operation of these is the same as for the rotary switches described in paragraph 267. **A momentary-contact switch** is also made for operating remote-control switches. The mechanism is similar to the regular push-button switches, except that the contact is made only as long as the button is pressed. Pressing the other button makes connection to another circuit. Both buttons cannot be pressed at the same time. When a button is released, the contact is opened with a quick break. **Automatic door switches** of the push-button type are also made. They have only one button and are installed in the jamb of the door. One type turns the lamps on when the door is closed and the other when the door is opened. Push-button switches are mounted in steel outlet boxes with suitable covers (Fig. 122*c*). Switch plates similar to those used for rotary flush switches are employed. Sometimes push-button switches are used on exposed conduit work. In such cases they are mounted in a cast-iron box (Fig. 130*c*). **Pendant switches** (Fig. 191) are a modified form of push-button switch arranged to hang from a pendant cord. They are used to control ceiling fixtures which are out of reach, and are cheaper than a regular wall switch.

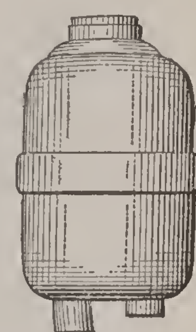


FIG. 191.—Pendant Switch.

271. Applications. Push-button switches are used more commonly for controlling branch lighting circuits than snap switches. The same rules apply with regard to the use of single-pole switches. For the best service, double-pole switches should be used. The cost of these is about 25 per cent more than single pole.

272. Remote-control Switches. These are magnetically operated switches. The contacts are opened and closed by electromagnets which are controlled (usually at a considerable distance) by means of a small two-throw knife switch or a momentary-contact push-button switch. Fig. 192 shows the method of operation. Remote-control switches are used with large fixtures to simplify the wiring since the point of control is usually a considerable distance away. If hand control is used, the main circuit, which must be of large size, would have to be run to the control point. If a remote control switch is used, it can be located at any convenient place near the fixture and only three

small wires need be run to the control point. This usually results in a considerable saving in copper for very large fixtures. The use of this switch has the further advantage that a push-button switch can be used for the control of large currents, whereas with hand control a knife switch would have to be used. This is more difficult to conceal, and more dangerous for an unskilled person to operate. Remote control switches are also sometimes used in connection with burglar alarms to throw on a part or all the lights in a residence, by the operation of a control

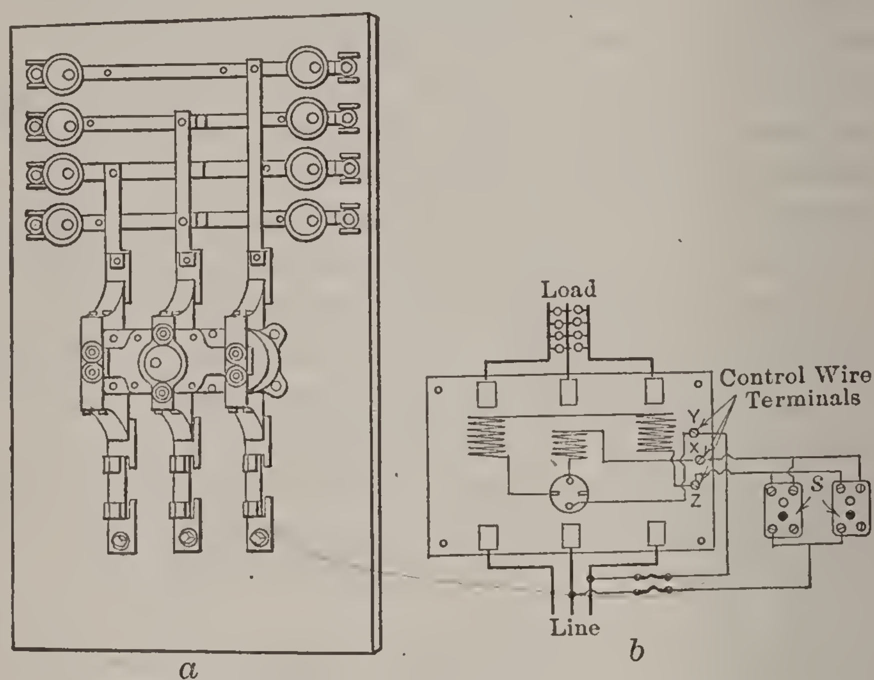


FIG. 192.—Remote-control Switch.

a. Front-connected switch with three-wire mains and four two-wire branches. *b.* Diagram of connections. Switches (*s*) are momentary-contact push-button switches which can be located at any convenient points. As shown, the switch could be controlled from two points. The trip circuit is X and closing circuit Z.

switch. Small motors, which do not require any starting rheostat, can also be started and stopped at a distance by this type of switch.

CIRCUIT BREAKERS—AIR-BREAK TYPE

273. Construction. The purpose of a circuit breaker is to open a circuit automatically whenever conditions on the circuit which it protects have become abnormal. Usually they are employed to open the circuit when the current exceeds a safe value, but they are sometimes used for other purposes, such as to open on reversal of current flow, failure of voltage, etc.

The contacts are held closed by a latch which is tripped by the armature of an electromagnet connected into the circuit. The spring action of the movable contacts, and in some cases additional springs, cause the contacts to open quickly. Ordinary **overload circuit breakers** (Fig. 193), which protect against excessive current, are most commonly employed. They are used for all d.c. voltages and when suitably designed may be

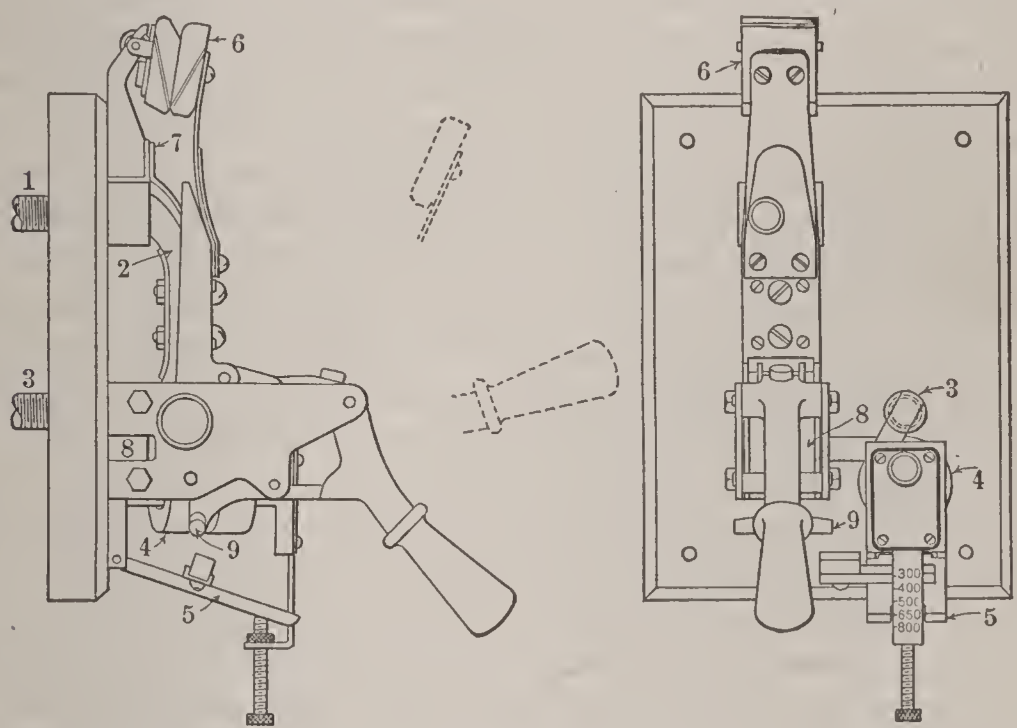


FIG. 193.—Circuit Breaker. Single pole, 600 volts, 400 amperes, plain overload.

Current enters at stud (1) and passes through laminated brush (2), lower contact block (8) and coil (4) and to stud (3). If the current exceeds the value for which the breaker is set, armature (5) is lifted by current in coil (4), thus striking arm (9) and unlatching the toggle. The breaker thus opens, taking the position shown in dotted lines. As the breaker opens, the brush leaves the contact block first, then (7) opens and finally the circuit is broken by the carbon contacts (6) so as to prevent burning of the main contacts. Breaker can be set to trip at a lower current by raising (5) .

used on alternating current. It is more common, however, to use oil circuit breakers* for alternating current. Circuit breakers are rated at the current which they will carry continuously without overheating and at the maximum voltage for which they should be used. The setting of a breaker can be adjusted to suit requirements, the range of setting for one standard line of breakers being from 80 to 160 per cent of the rating. Circuit breakers are made in many sizes to suit all

* See paragraph 276.

requirements from 25 amperes to 10,000 amperes or more. They are made one-, two-, three- or four-pole in the smaller sizes. Very large breakers are usually single pole. Multiple breakers have trip coils on all poles, the tripping of one pole opening all. In some cases, the breakers are so designed that they cannot be held closed if an overload exists on the circuit. These are required where no knife switch is used. The ordinary overload circuit breaker acts almost instantaneously and, hence, is more sensitive to momentary heavy overloads than is an enclosed fuse. For example, a 15-ampere enclosed fuse will stand a 50 per cent overload for about 1 minute, without blowing. A circuit breaker set at 10 amperes would trip as soon as the current reached this value. In fact, a circuit breaker must be set very much higher than the fuse rating to make the fuse blow before the breaker opens on a sudden over load. The amount of this increase would vary with the design of the breaker, but in one case it was found that the breaker had to be set at 90 amperes before a 15-ampere fuse would blow when the current was thrown on suddenly.

274. Applications. Circuit breakers must be used for circuits carrying currents larger than the approved sizes of fuses. The largest sizes of approved enclosed fuses are 600 amperes up to 250 volts and 400 amperes from 250 to 600 volts. Under certain conditions, the Code allows the installation of enclosed fuses in multiple for currents larger than the capacity of a single fuse (Rule 23*e*).* Circuit breakers are commonly used, even in small capacities, for motor circuits and similar places subject to frequent overloads. When a circuit is opened by means of a breaker, it may be restored more quickly and with practically no expense as compared with a fuse. The first cost of a circuit breaker is, of course, much greater than an equipment of enclosed fuses. Circuit breakers should always be used on switchboards to protect motor feeders, and in some cases they can be used to advantage even on lighting feeders. It is also frequently good practice to use them to protect individual motors, especially if of large size, although in this case fuses also must be installed, unless the equipment is subject to competent supervision (Rule 23*f*). When a breaker is used, the fuses would be made large enough to blow only if the breaker failed to operate. Circuit breakers should never be installed where they are exposed directly to the severe conditions which exist in cement or flour mills, plaster or

* See paragraph 281.

furniture factories and similar places. In such cases, oil circuit breakers or enclosed fuses are better. When installed in places where considerable dust or dirt may accumulate, the breakers should be cleaned regularly to keep the contacts in good condition and prevent overheating. In many industrial establishments, it is desirable to enclose the breaker in a steel cabinet for protection. Circuit breakers must not be set more than 30 per cent above the allowable carrying capacity of the wire, as given in Table 36, unless a fuse is used to protect the wire (Rule 23*e*).

Oil Circuit Breakers

275. Construction. With the air-break type of circuit breakers, just described, the arc formed when the apparatus opens is freely exposed in the air, and under some conditions this may result in a considerable fire hazard. The type of breaker to be described has all the current-carrying contacts immersed in heavy mineral oil, and the arc is broken at a considerable depth below the surface of this oil. As a result of this, the insulation of the breaker is very much improved, so that it can be made for very high voltages, and the different poles can be located close to each other without the danger of flashing across which exists with the air-type breaker. Since the arc is entirely beneath the surface of the oil, the danger from fire is practically eliminated. At the same time, the contacts and mechanism are easily protected from dust and dirt. The general arrangement of an oil circuit breaker is shown in Fig. 194. The arc which is formed when the contacts open is extinguished by the oil surrounding them. As used on a.c. systems, the arc is extinguished when the current is at the zero point of the wave. Oil circuit breakers are not satisfactory for use on direct current. They may be of the plain overload type, or by the use of relays may be made to open the circuit under any desired set of conditions. The breakers are made with one, two, three or four poles to suit various kinds of circuits. For small capacities and relatively low voltages, the contacts for all the poles are contained in the same tank. For larger breakers, especially for high-voltage service, each pole is located in a separate tank. Breakers of the overload type are opened by trip coils, which are either operated directly by the line current or through the medium of current transformers and

relays. While ordinary overload circuit breakers operate very much like the air-break type when subjected to heavy momentary overloads, it is easily possible by means of relays to retard the action of the oil circuit breaker to any reasonable extent, so that its action on overloads would resemble a fuse. This is an advantage in many cases where sudden heavy overloads occur, but where they last for so short a time that they are not dangerous and, hence, the circuit need not be opened. When breakers are so adjusted they are said to have a "time limit" characteristic. Oil circuit breakers are rated at the amperes which they will carry continuously and the maximum voltage for which they are safe. They can, of course, be used for any voltage less than this. Oil circuit breakers are also rated according to their breaking capacity; that is, a breaker connected to a large system has to be capable of interrupting a greater flow of power than on a small system. The required breaking capacity is, therefore, determined by the capacity in generators, transformers, etc., which is connected to the same busbars as the breaker. The manufacturer of the circuit breaker should be consulted where there is any doubt as to the size of breaker to be used. The trip coils can be set to operate at loads above and below the rating, a typical range being from 80 per cent to 160 per cent of rating. Some types of oil circuit breakers will not trip out upon an overload if the operating handle is held in the closed position. The best type of breaker is so

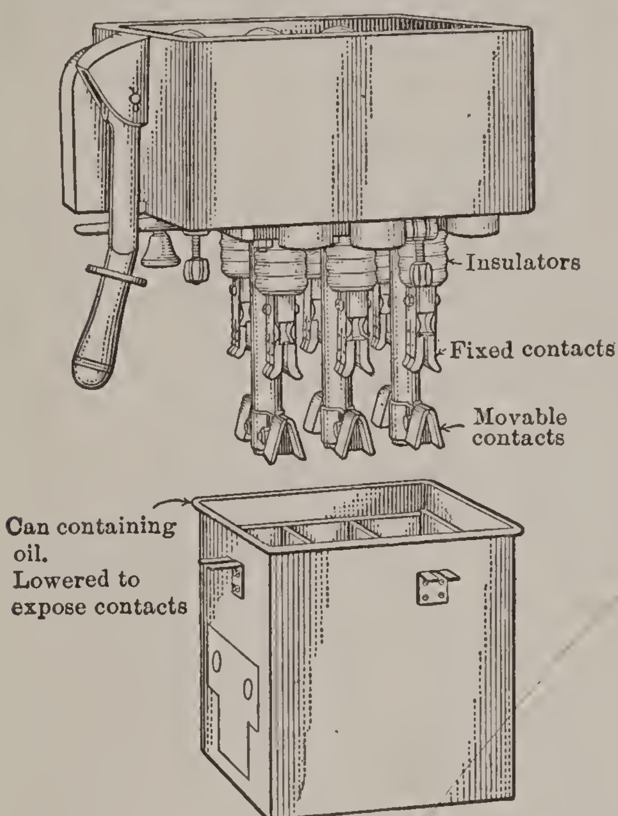


Fig. 194.—Oil Switch. (Three pole.)

The same device is also provided with trip coils to open the circuit automatically on overload. This type of switch is adapted for industrial applications for the control of induction motors at voltages not exceeding 2500 volts.

arranged that it will open immediately if closed when an overload exists on the line.

276. Applications. The Code rules regarding the use of air-type breakers apply also to oil circuit breakers. The advantages of the oil circuit breaker over the air-break type are: the absence of exposed arcing; protection from dust, dirt, etc.; greater compactness; better insulation and protection of live parts so that danger of shock is eliminated. For these reasons, oil circuit breakers are very commonly used for a.c. work up to 550 volts and are always used on higher voltages, except for very small capacity circuits. Oil circuit breakers are very commonly used for motor circuits, both on the switchboard and for the individual motors. Sometimes when enclosed fuses are used to protect the motor an oil switch is used for control. An oil switch is the same as a breaker, except that it does not have any automatic tripping mechanism, and must be operated by hand to open the circuit. Fig. 214 shows oil circuit breakers installed on a switchboard.

Open Fuses

277. Construction. The open fuse is the simplest device used for the protection of a circuit. It consists of a wire or strip made usually of an easily melted alloy, and so small in cross-section that it will melt before the line wires are overheated. At one time **fuse wire,** an alloy of lead, tin or other metals, was used. A short piece of this wire was clamped between two contact blocks which were mounted on an insulating base. It was soon found, however, that fuse wire was very unreliable, since drafts of air and variations in the lengths of wire used affected the melting-point of the fuse. The next step was to attach a definite length of fuse wire to copper terminals, thus forming a **link fuse** (Fig. 195). Later, links were made from strips of copper, aluminum, etc. For small sizes, the lead alloy link fuse is

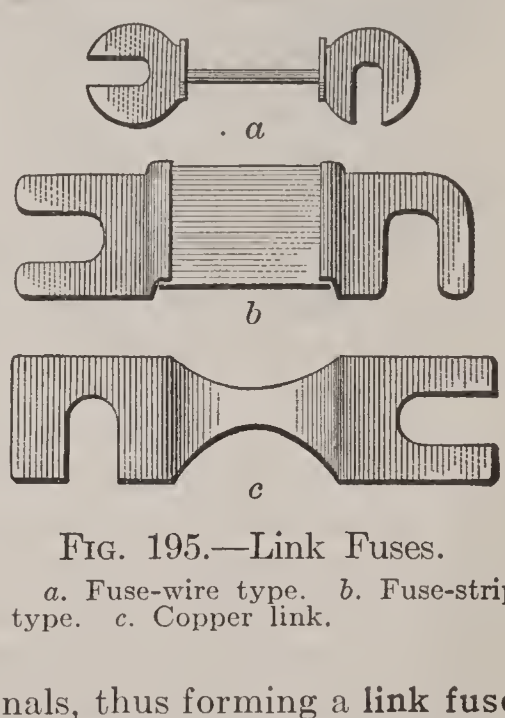


FIG. 195.—Link Fuses.

a. Fuse-wire type. *b*. Fuse-strip type. *c*. Copper link.

approved. For larger currents, copper or aluminum fuses are generally preferred. Link fuses will carry a current about 25 per cent above their rating without melting (Rule 68*b*).

278. Applications. Link fuses are used principally on switchboards or panel boards. They are seldom used in individual cutouts. The only advantage they have is the low cost. The disadvantages are that they are unreliable, cause a considerable flame when they blow, and soon disfigure the panel upon which they are mounted. They also may cause injury to a person nearby when they blow. Link fuses must always be enclosed in a metal box or cabinet, except when mounted on a switchboard (Rule 23*c*).

Enclosed Fuses

279. Plug Fuses. The earliest form of enclosed fuse was the Edison plug fuse. The type now in use (Fig. 196) is only slightly modified from the original design. It consists of a length of lead alloy fuse wire mounted in a porcelain cup with a mica cover. The contacts are the same as the medium-size Edison base for incandescent lamps. This plug fuse is made in various sizes up to 30 amperes for use on 125-volt circuits or 250–125-volt three-wire systems. It is not very accurate nor reliable because of the short length of fuse wire. It is also rather expensive, although considerably cheaper than the cartridge type of enclosed fuse. Plug fuses are used very extensively both in panel boards for branch circuits, and in individual cutouts of small capacity. The ordinary Edison plug fuse (Fig. 196) is not approved for 250-volt service. For this a regular cartridge fuse of the 0–30-ampere size is used. This is enclosed in a porcelain shell, which has standard plug fuse threads so that it can be used in a regular cutout. The maximum size for this type of fuse is 30 amperes. There is also a large size 250-volt plug fuse which is approved in sizes up to 60 amperes. This uses the regular 31–60-ampere size of cartridge fuse and is the same as the one just described except that it is larger. These plugs are used in large-size Edison plug cutouts.

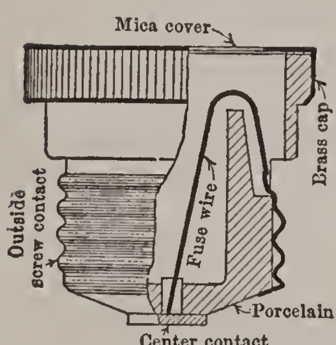


Fig. 196.—Edison Plug Fuse.

280. Cartridge Fuses. The most common type of enclosed fuse is the cartridge fuse. The current passes through a fusible link held in the centre of a heavy fibre tube (Fig. 197). This link is made of aluminum or zinc and is soldered to copper terminals which serve to make contact with the circuit. The shape

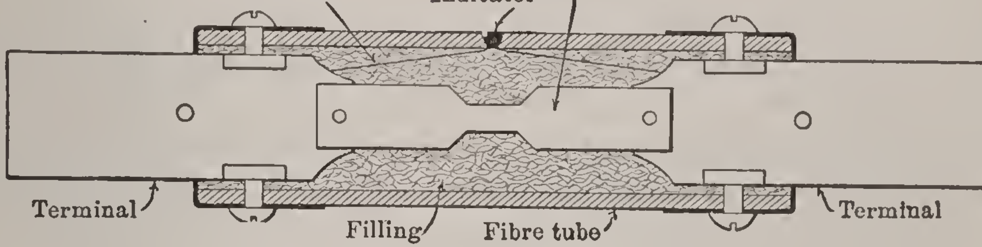


FIG. 197.—Sectional View of Cartridge Fuse.

of these links varies with the size of the fuse and with the manufacturer. The fuse link is surrounded by a filling which consists of porous, non-conducting material. Some manufacturers use the material in the form of a fine powder and others use a granular filling. When the fuse "blows" some of the metal of the link is vaporized and rendered conducting, so that an arc tends to form. The filling must quickly absorb this vapor and cool or condense it so that it is rendered non-conducting, and the arc thereby extinguished. Whiting, rotten stone, finely divided asbestos and other materials of a similar nature are used for filling. With the larger sizes of fuses, vents are provided in the end caps, to reduce the internal pressure when the fuse blows. For fuses up to 60 amperes* contact with the circuit is made by clips which grip the end caps (Fig. 198*a*). For larger sizes, the knife-blade contact is used (Fig. 198*b*). One difficulty with an enclosed fuse is to know

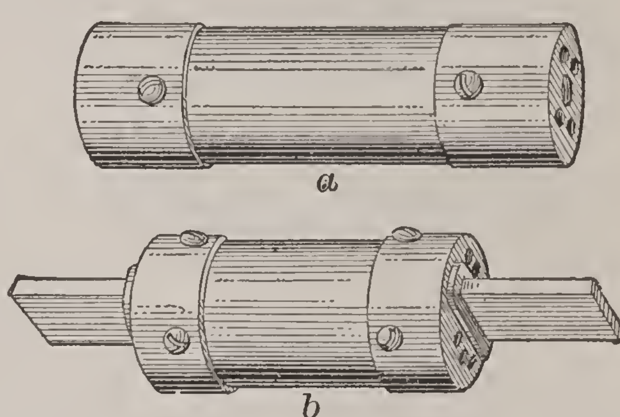


FIG. 198.—Enclosed Fuses. (Cartridge type.)

a. Ferrule contacts. *b.* Knife-blade contacts.

* National Electrical Code standard.

when it is blown. There are several types of **indicators** used for this purpose. In one of these, a small wire is attached to the terminals and carried outside the tube near the centre (Fig. 197). This wire is covered by the paper label, so that when the fuse blows the wire melts and leaves a burned spot in the paper. Another type has a portion of the end cap which moves out when the fuse blows.

281. Standard Sizes. The construction of approved enclosed fuses is carefully specified in the Code (Rule 68). There are two classes of fuses, one for circuits up to 250 volts and the other for 250- to 600-volt circuits. The 600-volt fuses are longer than the 250-volt fuses and will not fit the same cutouts. The dimensions of the various capacities of fuses are such that only a limited range of sizes will fit a particular size of cutout. The range is as follows:

Cut-out.	Sizes of Fuses.	
	250-volt.	600-volt.
30 amperes	3– 30 amperes	3– 30 amperes
60	35– 60	35– 60
100	65–100	65–100
200	110–200	110–220
400	225–400	225–400
600	450–600	not approved

From five to ten intermediate capacities of fuses can be obtained in each group. When fuses larger than those listed above are required, the Code allows the use of two or more fuses in multiple (Rule 23*e*), provided the fuses are all of the same size and the fuse clips are all mounted on a single busbar. This arrangement is not recommended, however, because of the difficulty in making each fuse take its share of the load. Unless care is taken to make good connection with each fuse, the current will be divided unevenly and the fuses will blow even when no overload exists. This arrangement is not allowed for motor circuits.

282. Action on Overloads. An enclosed fuse has a considerable " time limit " feature. That is, an overload which occurs

for only an instant would not blow the fuse, whereas if the overload continued for several minutes, the fuse would have time to heat up, and it would then blow. The action is, therefore, different from the ordinary overload circuit breaker, as was explained in paragraph 273. **The rating** of an enclosed fuse is the current value marked on the label. The construction rules (Nos. 68*h* and *i*) require that enclosed fuses shall carry indefinitely, under ordinary conditions, a current 10 per cent greater than this rating, and that with a current 25 per cent greater they shall open the circuit without exceeding a safe temperature. It is also required that with an overload of 50 per cent the fuses shall blow within the time specified below:

0– 30 amperes	1 minute
31– 60	2 minutes
61–100	4
101–200	6
201–400	12
401–600	15

The time given above is with the fuse cold at the start of the test. Under usual conditions, the fuse would be warm, from the regular current, so that the time to open an overload would be shorter than is indicated.

283. Refilled Fuses. Cartridge fuses, 65 amperes and larger, are refilled by the manufacturers at a price from one-half to one-third the price for new fuses. When refilled in this way they are guaranteed to be as accurate as new fuses and are approved by the Code. There are a number of so-called renewable fuses on the market, but none of them are at present (1916) approved by the Code. These fuses are made substantially like the standard cartridge fuse, except that the caps are easily removable for the purpose of inserting the fusible link and filling. From the standpoint of the Underwriters, the objection to the use of these fuses is that, in unskilled hands, the refilling may not be done properly, or too large a link may be used. It is probable that before long the use of these fuses will be allowed under certain restrictions.

284. Enclosed Fuse Cutouts. In order that the fuses may be easily replaced in the circuit, cutouts are provided. **Plug fuse cutouts** (Fig. 199), are made single, double and triple pole, for branch and main-line work. Contact is made with the

threaded shell into which the plug is screwed and also with an insulated stud at the bottom of the shell. Similar cutouts are frequently used on panel boards. **Enclosed fuse cutouts** (Fig. 200) are made single, double and triple pole for 250 volts in sizes up to 100 amperes. Larger sizes are single pole only. For 600 volts, only single-pole cutouts are usual. The method of making connection with the fuse is apparent from the illustrations. Where enclosed fuses are used on panel boards or switchboards, the same style of contact clips is used, the terminals being modified to suit the requirements and assembled directly on the slate or marble panel.

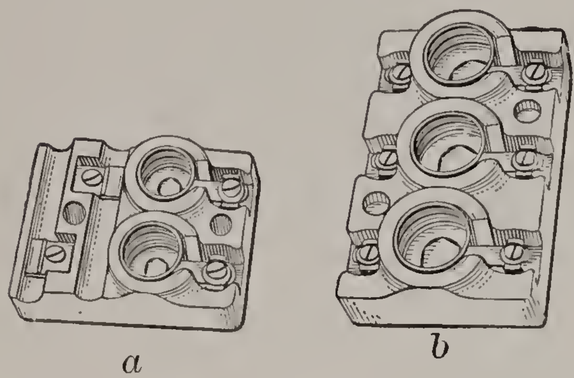


Fig. 199.—Plug Fuse Cutouts.

a. Double-pole branch cutout. *b*. Triple-pole main-line cutout.

285. Applications. Where a fuse is to be used to protect a circuit, the enclosed type is the best. Link fuses are allowed only under special restrictions. They are also unreliable in action. The plug fuse is satisfactory for small-capacity circuits, but, in general, the cartridge fuse is most commonly used. For moderate sizes, approved enclosed fuses are reliable and entirely satisfactory. For large circuits, the cost of the fuse and the drop in voltage is considerable. Furthermore, when a large number of fuses are mounted on a switchboard or panel board, there is difficulty in quickly locating a blown fuse and in replacing it. This may result in long delay in restoring the service. One especial advantage of fuses is that they will not blow on

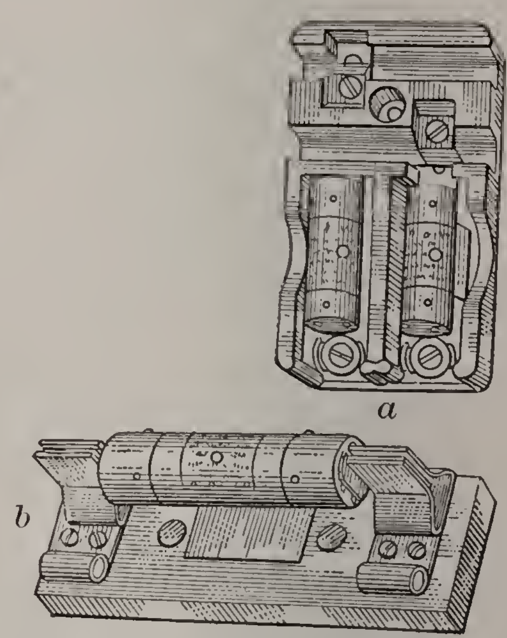


Fig. 200.—Enclosed Fuse Cutouts.

a. Double-pole branch cutout. *b*. Single-pole main-line cutout.

heavy momentary overloads, which might trip a circuit breaker unless it was set so high that it would not give proper protection to the circuit against moderate overloads lasting a considerable time. Momentary overloads, even if quite heavy, usually do no harm to a motor or other apparatus, as there is not time enough for the machine to overheat. Hence it is desirable not to open the circuit in such cases. On the other hand, a moderate overload, if continued for a considerable time, will finally overheat the machine, and, therefore, the circuit should be opened before this occurs. In general, it may be stated that fuses are best adapted for lighting circuits, except for very large currents and for small motors such as would be used for individual machine tool drive, or for ordinary group drive. For large motors, or where the duty is severe, as on cranes, hoists, bending rolls, etc., circuit breakers would be used. Fuses must also be used in such cases (Rule 23*f*), in addition to the circuit breaker. The fuse protects the motor against overheating and the circuit breaker takes care of excessive momentary overloads. In switchboards, or where the apparatus is under proper supervision, both fuses and circuit breakers are not required on the same circuit.

CHAPTER 16

SOCKETS AND RECEPTACLES

286. The purpose of a socket or receptacle is to provide means by which an incandescent lamp may be readily connected to a circuit and replaced when burned out. The sockets and receptacles usually employed are arranged to take lamps with Edison bases of the three sizes previously mentioned.* The construction of sockets and receptacles is carefully specified by the Code, and only devices which meet these specifications are approved for use. Sockets are designed to screw on to a pipe or to be suspended by a flexible cord. Receptacles are designed to attach to a wall or other flat surface such as the cover of an outlet box, etc.

287. Sockets. Key sockets are used where it is desired to control the lamp at the socket (Fig. 201*a*). Usually only one

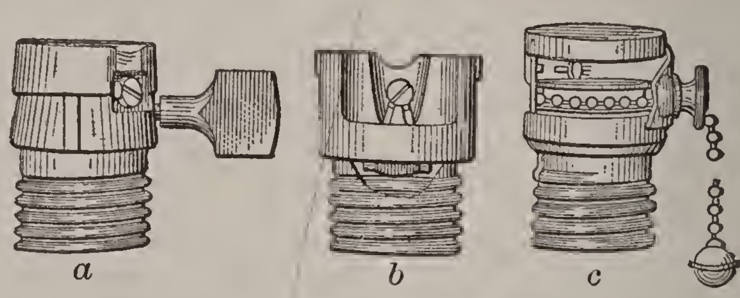


FIG. 201.—Socket Bodies. For brass shell sockets. (See Fig. 202 for illustration of shell and cap.)
a. Key socket. *b*. Keyless socket. *c*. Pull socket.

side of the circuit is opened at the key, but double-pole sockets which open both sides of the circuit are made by some manufacturers. **Pull sockets** (Fig. 201*c*), have a rotary contact device which is operated by a chain. These are convenient for use where the socket is out of reach. They cost nearly twice as much as the ordinary key socket. **Keyless sockets** (Fig. 201*b*)

* See paragraph 11.

are similar in construction to the key sockets already described with the key and contacts omitted. They would be used on fixtures where the lamps are controlled from separate switches. Keyless sockets cost about 10 per cent less than key sockets. Sockets for ordinary interior wiring have a brass shell and a cap which can be finished to match the decorations in the room (Fig. 202*a*). **Porcelain sockets** (Fig. 202*b*) have a porcelain shell, a metal or porcelain cap and a porcelain insulated key if any is used. They are liable to breakage and are, therefore, not approved where subject to rough usage. They are used in bathrooms and basements where there would be danger of a shock from a brass-shell socket. Sockets may be obtained with caps threaded to fit $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$ or $\frac{1}{2}$-in. iron pipe. Where they are hung from a flexible cord, not less than a $\frac{3}{8}$-in. size socket should be used and the opening provided with an insulating

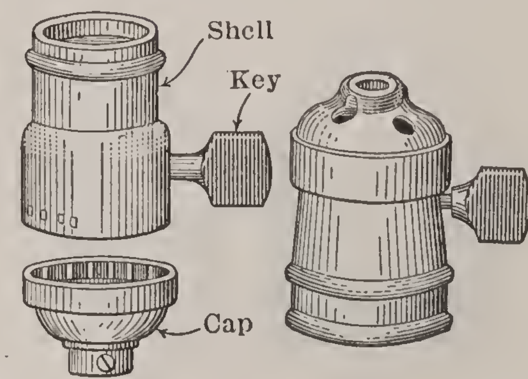


Fig. 202.—Sockets.

a. Brass shell socket with cap removed to show projections which serve to clamp the two parts together. *b.* Porcelain socket for pendant cord.

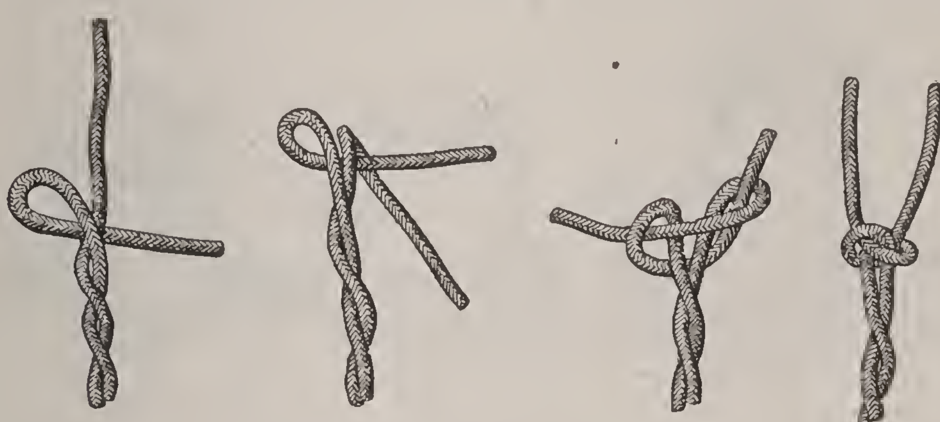


FIG. 203.—Method of Tying an "Underwriters'" Knot.
The first fold should be carried *behind* the straight wire.

bushing (Rule 31*d*). The cord must have a knot inside the socket cap to support the weight of the lamp and reflector so that there will be no danger of pulling the wires out of the contact clips. Fig. 203 shows the method of tying this knot.

Weatherproof sockets (Fig. 204) are made with aluminum, porcelain and moulded composition shells. These sockets are keyless. The aluminum and porcelain-shell sockets can be obtained with caps threaded for $\frac{1}{8}$, $\frac{3}{8}$ or $\frac{1}{2}$-in. iron pipe sizes. The porcelain and moulded composition sockets can be obtained with the connection wires directly attached, ready for fastening to the branch circuit. In this case, the socket is supported by the lead wires. **Mogul sockets** are used for large tungsten lamps having mogul bases. These sockets are keyless and have metal or porcelain shells. They are also made in the weatherproof form, with porcelain shells. **Candelabra and miniature sockets** are made both key and keyless (the latter most commonly used), with metal or porcelain shells. They are also made in the pull type. Miniature sockets are allowed only for decorative lighting systems, Christmas tree lighting outfits, and sim-

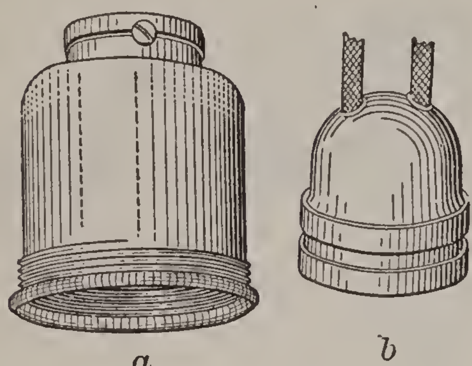


FIG. 204.—Weatherproof Sockets.

a. Aluminum shell socket. *b*. Moulded mica socket. For voltages up to 600 volts.

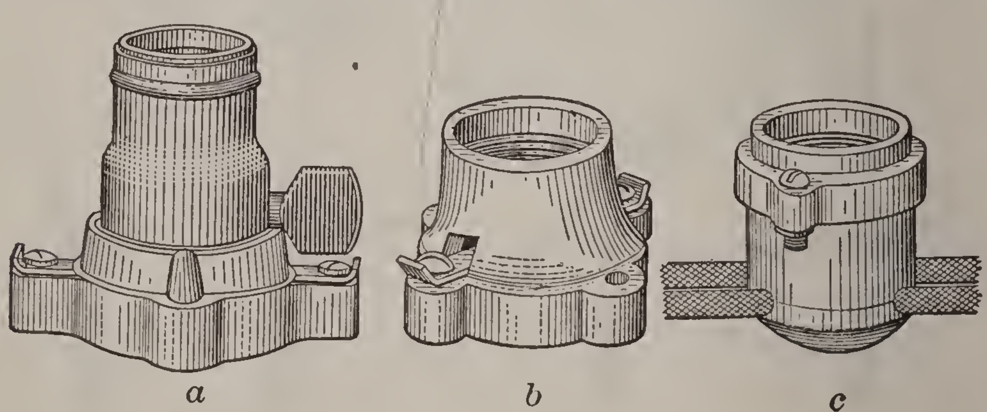


FIG. 205.—Receptacles.

a. Key, cleat receptacle. *b*. Keyless, porcelain receptacle. *c*. Sign receptacle. For voltages not exceeding 250 volts.

ilar purposes. **Receptacles** are made in a large variety of styles. One style consists essentially of a regular brass socket shell and body mounted in a flat base (instead of a cap) so that the device can be placed on a flat surface or on an outlet box.

This style can, therefore, be of the key, keyless, or pull type (Fig. 205*a*). Another style is made of a single piece of porcelain in which the contacts are mounted. The style shown in Fig. 205*c* is for mounting in the cover of an outlet box or in an opening in a sheet metal sign. Another style (Fig. 205*b*) is mounted on the surface of a wall.

288. Rating of Sockets and Receptacles. Sockets and receptacles which are approved by the Code must be stamped with the maximum voltage and watts for which they may be used. The rating thus marked is in accordance with the following classifications (Rule 72*a*):

RATINGS OF SOCKETS AND RECEPTACLES

Class.	Key.			Keyless.		
	Watts.	Volts.	Max. Amp.	Watts.	Volts.	Max. Amp.
Candelabra base..	75	125	0.75	75	125	1
Medium base....	250	250	2.5	660	250	6
Medium base (*a*).	660	250	6	660	600	
Mogul base......	....	....	......	1500	250	

(*a*) This rating allowed only where switch mechanism gives a quick "make" and "break" action.

In explanation of note (*a*) it may be said that the ordinary key socket or receptacle has a mechanism which closes or "makes" the circuit slowly but gives a quick "break." This type would, therefore, be rated at 250 watts. The 660-watt socket is only slightly more expensive.

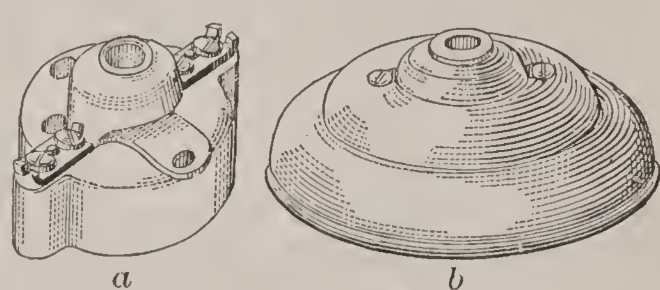


FIG. 206.—Rosettes.

a. Cleat rosette. *b*. Concealed rosette for use with outlet box.

289. Rosettes. Where an ordinary flexible cord drop is used (Fig. 24), a rosette is provided to support the cord and socket. Devices similar to Fig. 206*a* are used for cleat work. Fig. 206*b* shows a very satisfactory style for concealed work. This

rosette attaches directly to the outlet box. In all these devices the cord passes through a central hole and is anchored by a knot (Fig. 203), to relieve connections of any strain. The cord is then attached to contacts inside the porcelain body. Rosettes are usually made fuseless, as fuses are not, in general, allowed in rosettes (Rule 23*d*). For open wiring in large mills, the Code allows the use of link-fuse rosettes for 125 volts and enclosed fuse rosettes for 250 volts. The fuses must not be larger than 3 amperes and the fuse in the branch circuit not over 25 amperes.

290. Plug Receptacles. For attaching portable apparatus, such as heaters, fans, etc., plug receptacles are used. They may

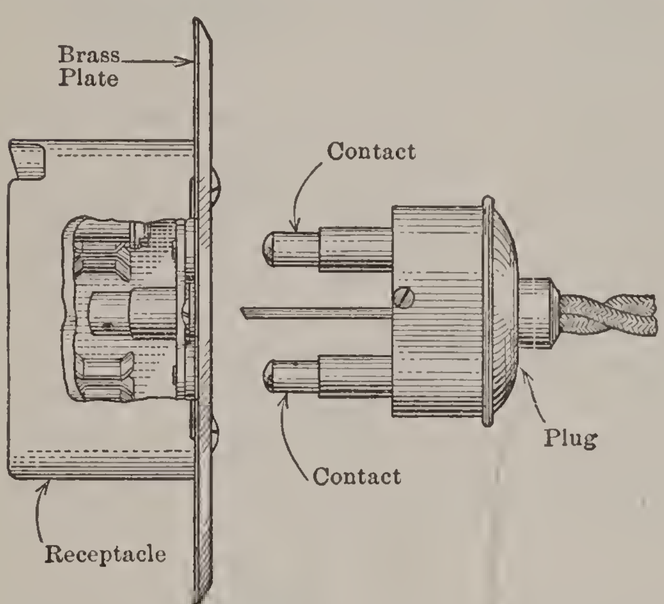


Fig. 207.—Wall Receptacle and Plug.
For flush mounting in a steel outlet box. View shows porcelain cut away to show contacts. The centre prong on plug enters first and uncovers the opening in the plate for the contacts to enter.

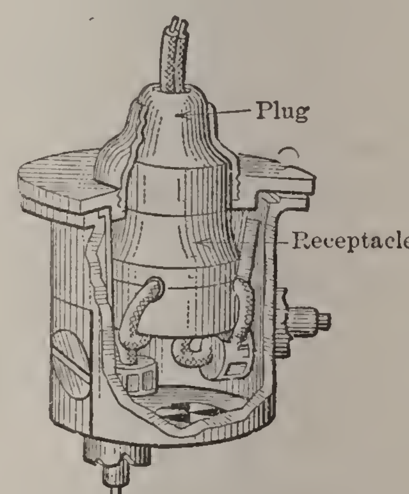


Fig. 208.—Floor Box.

be either of the wall or the floor type. **Wall receptacles** are generally of the flush type and take the same size of outlet box as push-button switches. The usual type carries spring clip contacts arranged to engage corresponding contact posts on **an attachment plug** which is connected to the flexible cord (Fig. 207). One style of plug receptacle contains regular Edison lamp base contacts. In this a screw plug is used. **Floor receptacles** (Fig. 208) are similar to the wall receptacles, as far as the electrical parts are concerned, but the outlet box must be made waterproof.

CHAPTER 17

PANEL BOARDS AND SWITCHBOARDS

291. Since the Code requires that for branch lighting circuits, not more than 660 watts (or under special conditions 1320 watts) can be dependent upon one cutout (Rule 23*d*), it is apparent that for all installations, except the very smallest, there must be a considerable number of branch circuits, each having separate fuses. With motors, the same holds true to a considerable extent, since every motor must be protected by individual fuses (or circuit breakers). When there are a large number of these branch circuit cutouts required, it is generally customary to group them together as far as possible for convenience in renewal of fuses, and control of the circuits. This requires the use of **panel boards** which contain the essential fuses and control switches when these are essential. The panels are enclosed in metal cabinets and are set flush with or on the surface of the wall. **Switchboards** are not enclosed in cabinets. They contain the various switches and fuses which control the feeders for an installation. In general, they are

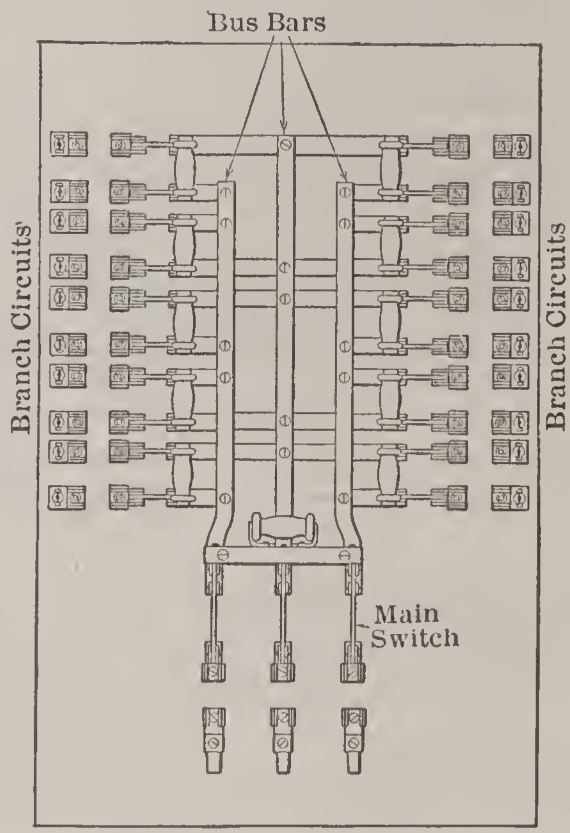


Fig. 209.—Lighting Panel Board. Ten circuit.

Three-wire mains and two-wire branches. Switches and fuse clips in both branches and mains. Fuses not shown. Frequently switch and fuses in mains are omitted.

larger than the panel boards, and no branch circuits are supplied directly from them.

292. Cutout Cabinets. For a small number of lighting circuits, individual cutouts enclosed in cabinets are used to protect the branch circuits. They are usually installed in cast-iron or sheet-metal boxes.

Lighting Panel Boards

293. Construction. Regular panel boards, such as are generally used for branch lighting circuits, have all fuse clips and connections mounted on a single panel and connected to a set

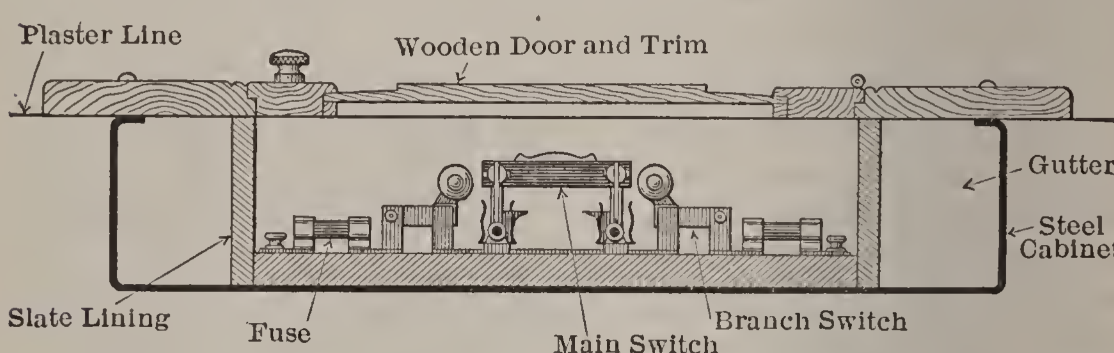


FIG. 210.—Sectional View of Lighting Panel Board and Cabinet. Flush-mounted Type.

of copper busbars (Fig. 209). The branch circuit fuses may be either the Edison plug type or the cartridge type, as shown. Open-link fuses are still allowed by the Code, but they are seldom used in new work, and are not recommended, because of the damage which occurs to the panel board if fuses blow frequently. There is also the possibility of communicating fire if the door is left open. If the branch circuits are provided with **switches**, these may be of the knife-blade type, as shown in Fig. 209, or snap switches or push-button switches may be used. Knife switches should have a 30-ampere rating, to be substantial mechanically, although usually not more than 6 amperes is carried by the switch. For snap or push switches, the 10-ampere size would be used. Switches are not necessary on the branches unless the lights are controlled at the panel board. Knife switches are more satisfactory mechanically, but there is more danger of the operator receiving a shock than with the other styles of switches. The circuits should not be controlled

at the panel board where the operation is in the hands of unskilled persons or the general public, because of the danger from shock and from tampering with the circuits. The switches are usually located between the busbars and the fuses (Fig. 210). In many cases, it is desired to group the control switches, but at the same time not allow access to the panel board. An excellent arrangement of this kind consists in mounting push switches in the cabinet and flush with the cover, so that the switches may be operated without opening the door of the cabinet. This is a good arrangement for stores. Each branch circuit should be numbered and a list of the circuits and the location of the lamps they supply should be mounted on the inside of the panel board door. The size of the busbars is determined by allowing 660 watts per branch circuit (or 1320 watts if double-size circuits are used). If other panel boards are supplied from the same busbars the load on these panels must be included. **Main switches and fuses** (Fig. 209) are not generally necessary, but are convenient for the purpose of cutting off all the circuits, so that repairs can be made without disturbing any other panel boards which may be connected to the same feeder. In cases where two or three panels are carried on the same feeder, it is common to supply the largest panel directly from the feeder, and to run mains from cutouts located on this panel, to the other panel boards. When this is done, these circuits should be connected back of the main switch and fuses. The panels are generally made of slate, although marble is sometimes used. The slate should be at least $\frac{7}{8}$ in. thick for panels having about fifteen circuits or less; larger panels should be $1\frac{1}{4}$ in. thick.

294. Cabinets and Trim. Panel boards are enclosed in sheet-steel boxes or cabinets which are open at the front and are large enough to contain the panels and leave room at the sides for the wiring (Figs. 210 and 211). When properly designed, it should be possible to install the panel after the cabinet has been erected. Cabinets are made for mounting on the surface of the wall or for flush mounting (Fig. 210). Cabinets with gutters are usually about 4 in. deep. **Gutters** are generally provided in cabinets for running the branch-circuit wires (Figs. 210 and 211). This space should be at least 3 in. wide and should extend around all four sides of the panel. Sometimes the wiring space is provided behind the panel. A gutter or equivalent wiring space is required when there are more than four branch circuits, unless

each circuit leaves the cabinet directly in line with its branch cutout. Usually this cannot be done, since most of the circuits enter either at the top or bottom and must be carried around the sides of the panel (Fig. 211). The gutter is separated from the panel by a slate **frame** which is made easily removable to facilitate connecting the circuits. These frames should be at least $\frac{1}{2}$ in. thick. The cabinets are closed by a **matt or trim** which contains the door. This door is the same size as the panel, so that when open the gutter is not exposed. For flush mounting the trim projects a slight distance beyond the edges of the cabinet to cover any small break in the plaster (Fig. 210). Both steel and wood trims are used. For industrial plants, etc., steel trim would generally be used. For office buildings, stores, etc., wood trim to match the finish is more common.

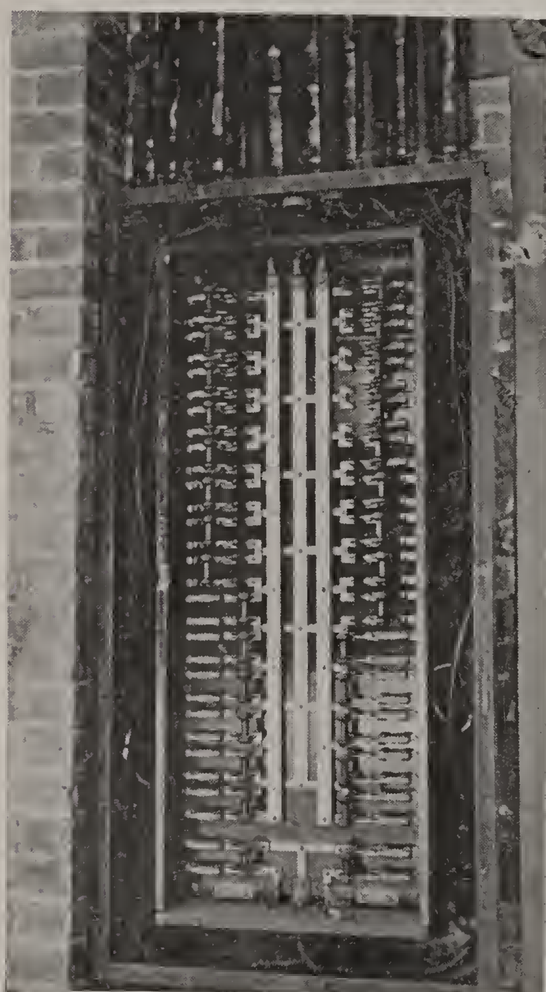


FIG. 211.—Lighting Cabinet, with Trim Removed.

Showing method of carrying wires through gutter from branches to conduit.

295. Types and Sizes of Panel Boards. Standard lighting panel boards are made for two-wire, 125- or 250-volt branches, with mains, or busbars arranged for two-wire, three-wire or three-phase supply. As a rule, the double-branch type (Fig. 209) is most satisfactory, because it gives a better proportion for the door, but for a small number of circuits where only a narrow panel could be used, single-branch panels, having branches only on one side of the busbars, may be used. The spacing of the parts on a three-phase panel is different from a three-wire board, so that care should be taken in ordering. Standard panel boards are made with

from two to thirty-two circuits. When a greater number of circuits must be controlled from one point it is best to use double panels with two doors. The dimensions of panels and cabinets vary somewhat with different manufacturers, but the dimensions given in Table 37 are representative of good practice.

296. Power Panel Boards. When there are a number of motors which can be conveniently supplied from one distributing point, a panel board may be used to supply the branches. The arrangement is similar to lighting panels except that the branch circuits are usually larger than 30 amperes (Fig. 212). These panels must be made to order because of the range in capacity required. The branch circuits must be provided with fuses. Knife switches are also desirable so that the motor control equipment and branch wiring can easily be cut off for inspection or repairs. Knife switches and fuses in the main busbars are not necessary unless other panels are supplied from the same feeder. In some cases, circuit breakers are mounted on panel boards. **The cabinets** used for power panel boards are of the same general design as for lighting panels, except they are usually larger. If circuit breakers are used, an ample space must be left between the breaker when open and the cabinet or the door.

FIG. 212.—Power Panel Board.
For a 115-volt, two-wire, d.c. system.

297. Switchboards. We are concerned here only with switchboards for the control of lighting or power feeders. Where the installation is small, a service switch and cutouts are all that is required (Fig. 229). For large installations, whether supplied from an isolated plant or a central station, there will be required a number of feeders, which must be brought together at the point of supply and separately controlled. In large office buildings, etc., the switchboards required for these feeders

reach large proportions. **The panels** used for switchboards are commonly slate or marble and are 2 in. thick, except for small installations. They are supported on a pipe or angle iron framework. Back-connected switches and circuit breakers are used so that all connections are made in the rear of the board. For lighting feeders the usual arrangement is to provide a knife switch and fuses for each feeder. The fuses should be mounted

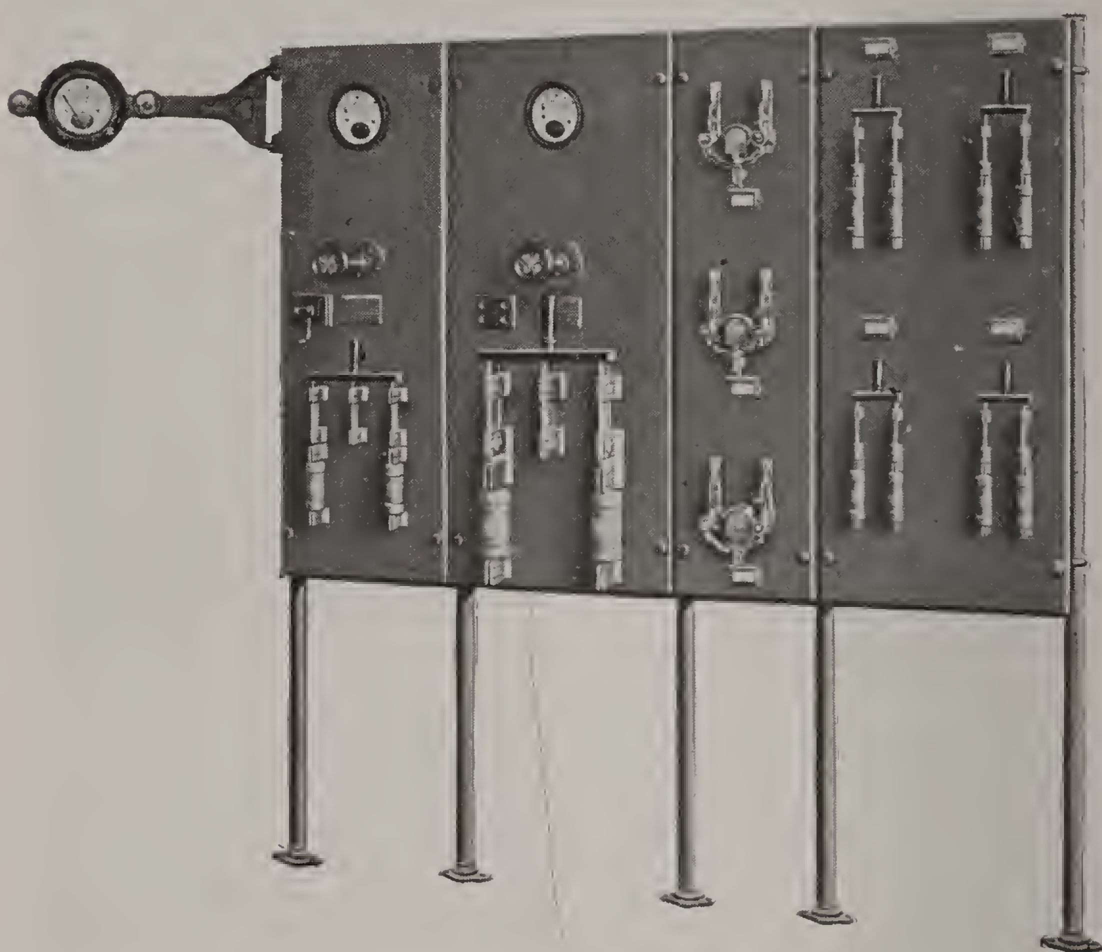


FIG. 213.—Typical D.C. Switchboard.

From left to right the arrangement is: Two generator panels, one power feeder panel with circuit breakers for three feeders, one lighting feeder panel with fused knife switches for four feeders. (General Electric Co.).

preferably on the front of the board if there is room. For power feeders, a switch and fuses are often used, but, in general, a circuit breaker is better for the reasons given in paragraph 274. If an oil circuit breaker is used, the switch is omitted, since the breaker takes its place. It is also possible to obtain circuit breakers which will trip out if closed on an overload, and in such cases the switch may be omitted. Oil circuit breakers are, in

general, better for use on a.c. power circuits than carbon breakers, because the latter require considerable space between adjacent breakers to avoid danger from a flash at one breaker spreading to another. For economy of space, it is generally necessary to place two or sometimes three breakers on the same panel one above another. With carbon breakers, there is great danger of the flash from one breaker spreading to those above and causing

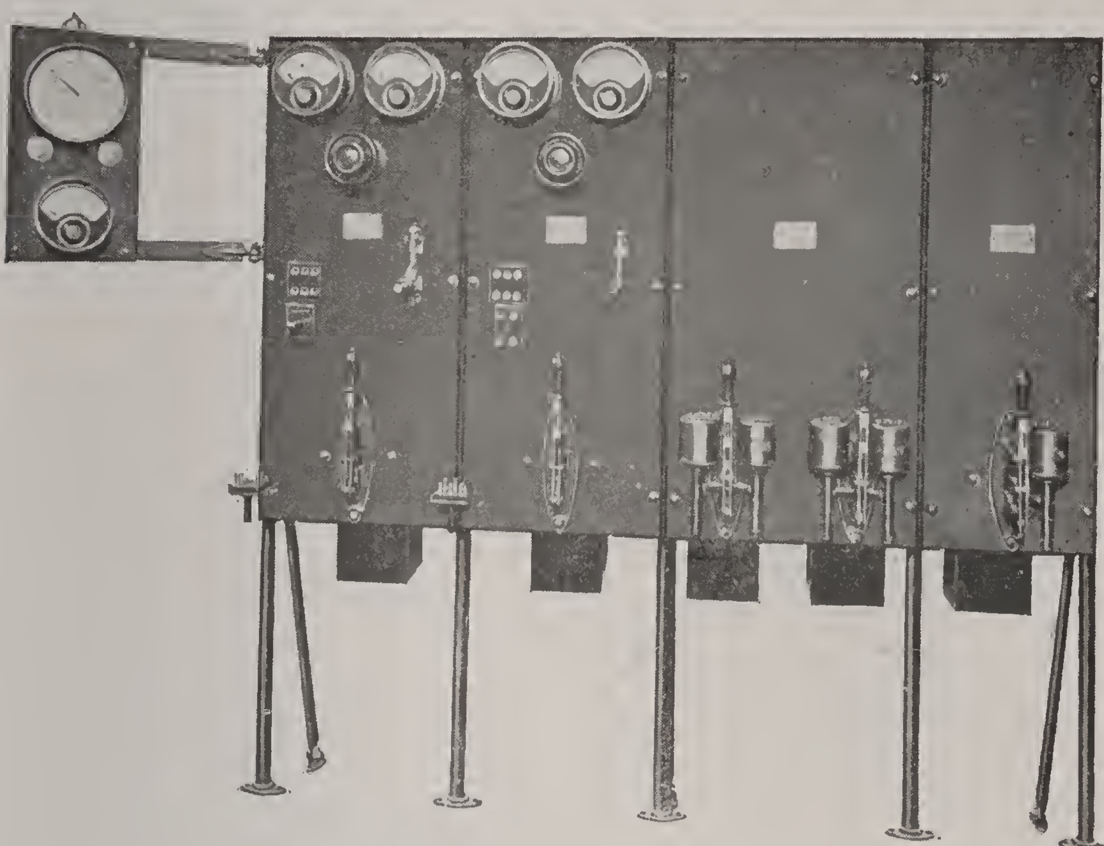


FIG. 214.—Typical A.C. Switchboard.

From left to right the arrangement is: Two generator panels with non-automatic oil switches, one three-phase feeder panel with automatic oil circuit breakers for two power feeders, one single-phase feeder panel with automatic oil circuit breaker for a lighting feeder. (General Electric Co.).

a short-circuit. Typical switchboards for small isolated plants are shown in Figs. 213 and 214. It will be noted that enclosed fuses and carbon circuit breakers are used for the d.c. board and oil circuit breakers for the a.c. board. The same general plan is followed for large installations where, however, more instruments are generally used. For a system using central station service, the switchboard shown in Fig. 228 is representative. Fuses or circuit breakers should be adjusted for the maximum current allowed for the particular feeder, in accordance with

Table 36, regardless of the fact that the actual load may be considerably less. This reduces the probability of the circuit being opened. **Meters** are sometimes used on feeder switchboards. There is not much need for ammeters on lighting feeders, but for power feeders they are useful and are frequently employed. A voltmeter equipped to read grounds on the system is a convenience. It is usually desirable to provide watt-hour meters for the lighting and power loads and in some cases for individual feeders. Only by this means can a proper record of the operation of the system be kept.

CHAPTER 18

ARRANGEMENT OF CIRCUITS

298. Parts of a Circuit. The connection between the point of supply and the individual lamps or motors is made by means of feeders, mains and branches. The **feeder** (Fig. 215) is the part of the circuit between the switchboard and the first dis-

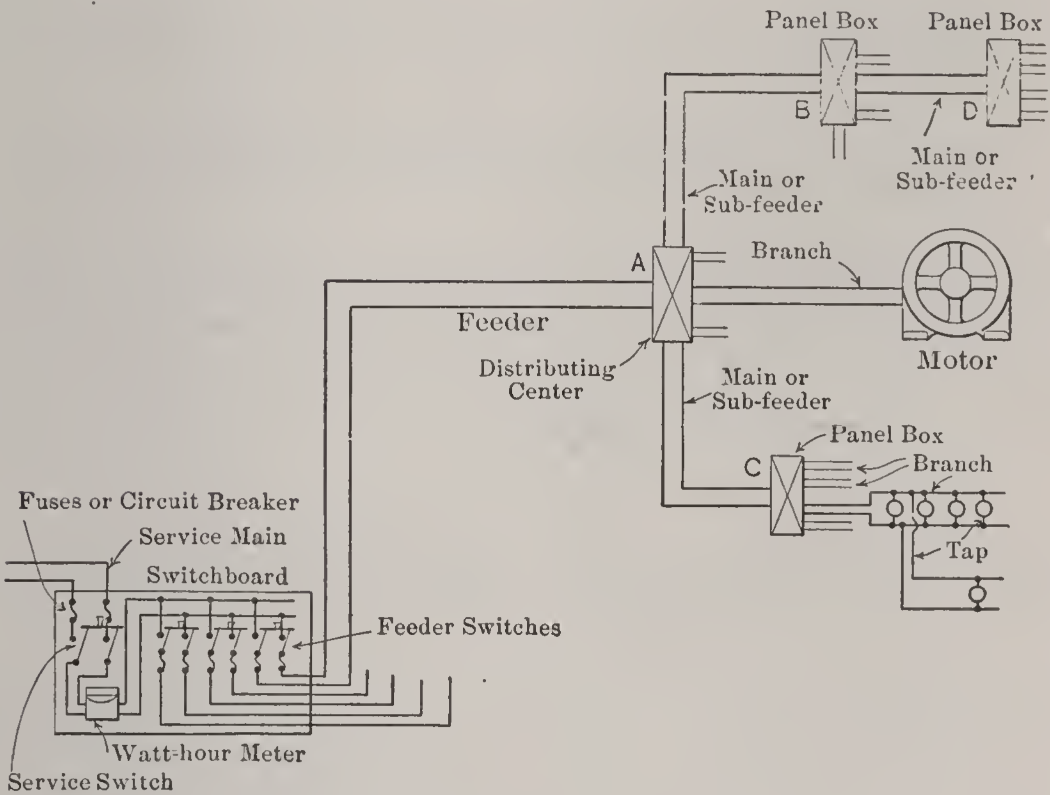


FIG. 215.—Parts of a Circuit.

Fuses and switches for branch circuits and mains not shown. Usually motors are run on separate feeders and not on a lighting feeder as shown.

tributing centre (*A*). The feeder is usually the longest part of the circuit. The **mains** (sometimes called sub-feeders) connect the first distributing point (*A*) with the other points (*B*, *C*, *D*, etc.). Sometimes there are no mains. The **branches** supply individual motors or groups of lamps. In general, as the mains are smaller than the feeder, fuses are required at the junction

point *A* to protect these mains. The branches must also be fused to protect the lamps or motors. When the electricity is supplied by a central station, a **service or service mains** are run in from the street circuits to the switchboard in the building. This service and the meter for recording the amount of electricity consumed are installed by the central station company, usually without charge to the customer, except where there are special conditions such as a long service or where special transforming devices are required.*

299. Main and Feeder Systems. The simplest arrangement of **lighting circuits** is shown in Fig. 216. The mains are run the

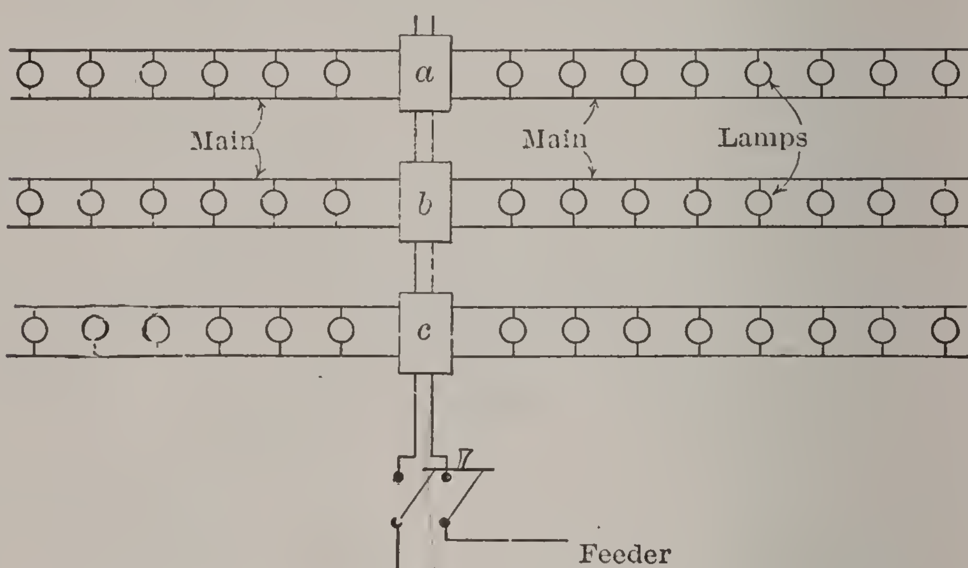


FIG. 216.—Lighting System. Using mains and fused rosettes.

length of the room and the lamps are supplied directly through fuses in the rosette used with each lamp. The mains are protected by fuses in the cutouts, *a*, *b* and *c*. This arrangement was at one time quite common for mill work and is still allowed by the Code for such places. The disadvantages are that the fuses in the rosettes are likely to give trouble, and the rosettes are frequently in such locations that it is difficult to replace blown fuses. Also, groups of lamps cannot be controlled separately, as is often desirable. Furthermore there is likely to be a considerably lower voltage on the lights at the ends of the mains. A better arrangement (generally employed at present) is to install the lamps without individual fuses, in groups taking not more than

* See paragraph 305.

660 watts (or in special cases, 1320 watts*). The branch circuit supplying this group is then run back to a distributing centre or panel board, where fuses are provided (Fig. 217). This panel board would be located in an accessible place to facilitate replacement of the fuses. This arrangement gives greater uni-

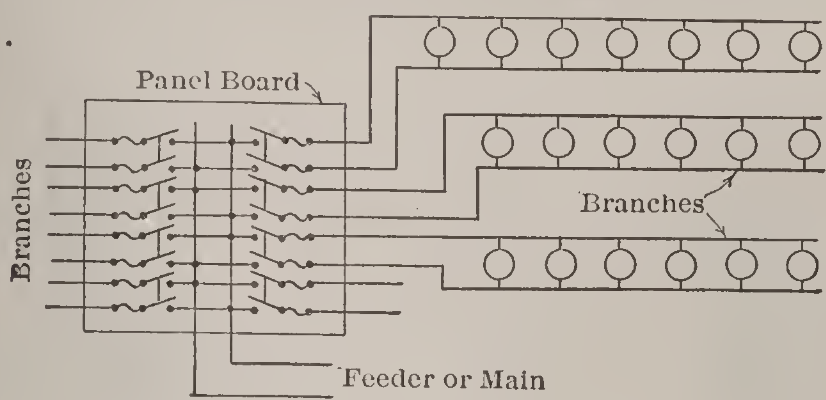


FIG. 217.—Lighting System.
With panel board and branch circuits.

formity of voltage at the lamps and makes their control more flexible. For **power circuits**, feeders are frequently run the entire length of a building and branch circuits for individual motors tapped off at different places (Fig. 218). When there are several motors close together, a better arrangement is to use

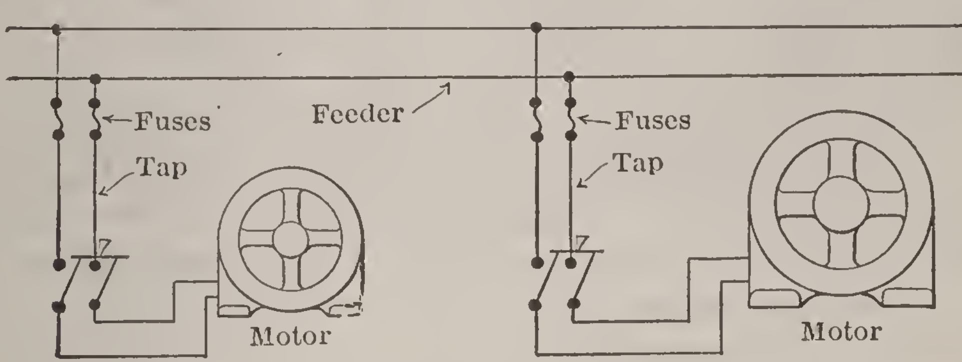


FIG. 218.—Power System.
Showing method of tapping directly from feeder. Starting devices not shown.

panel boards similar to those used for lighting, except that they are of larger capacity. The advantage of this method is that the cutouts for the branch circuits can be placed in a readily accessible position, where they can be properly enclosed and

* See paragraph 303.

protected. With the arrangement shown in Fig. 218, the cutouts would be scattered over the building and would frequently be located in inaccessible places. As a rule, more than one panel board is connected to a single feeder, for the sake of economy in the installation. The **method of feeding the panel boards** will depend upon the size of the building and the charac-

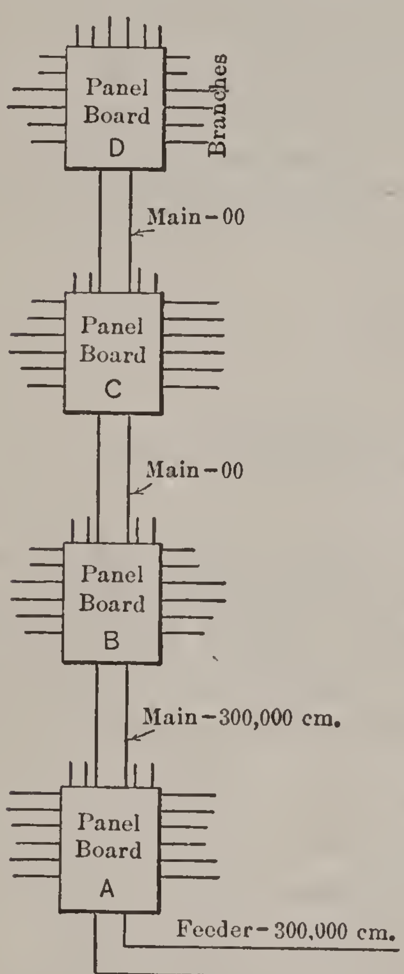


FIG. 219.—Feeder System for Small Buildings.
Showing use of a single feeder.

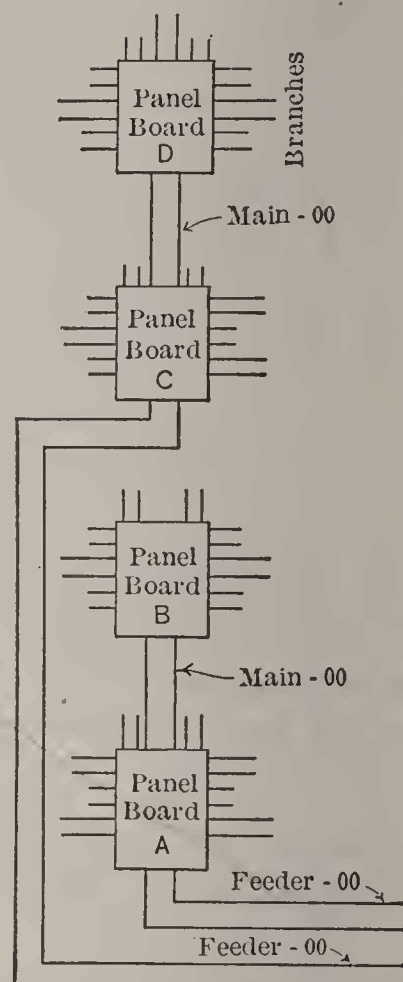


FIG. 220.—Feeder System for Small Building.

ter of the service supplied. For small office buildings and industrial establishments where only a few floors are to be supplied, the arrangement shown in Fig. 219 is used. This method has the disadvantage that the voltage of the lamps on the upper floors is lower than on the others because the drop cannot be equalized. Also it is not possible to control a portion of the lights separately from the switchboard. The mains connecting the panels are usually made smaller than the feeders (Fig. 219),

and, therefore, fuses would be required at the point where each main starts. Panel board D, for example, might have several sets of fuses between it and the switchboard, and the chance of trouble is thereby made greater. A better arrangement is shown in Fig. 220. It would be possible, by this method, to get the same drop on each feeder, so that the voltage at all the panel boards would be practically the same. Besides this, it is possible to control a portion of the lamps or motors independently of the others. Usually it is most economical to supply not more than three panel boards from one feeder, but no exact rule can be given. The arrangement for an office or loft building or similar service is shown in Fig. 221. The best arrangement is that in Fig. 221a, because it gives more uniform voltage. In large buildings, the floor area is so great that all the lamps or motors on a floor cannot be supplied from a single panel board without excessive drop in the branches. Where a number of panel boards are located on the same floor, it is best, if possible, to feed them vertically in groups as shown in Fig. 222. It sometimes happens that it is necessary to carry an entire floor on one feeder so that the power can be metered and controlled independently. For such requirements, the method shown in

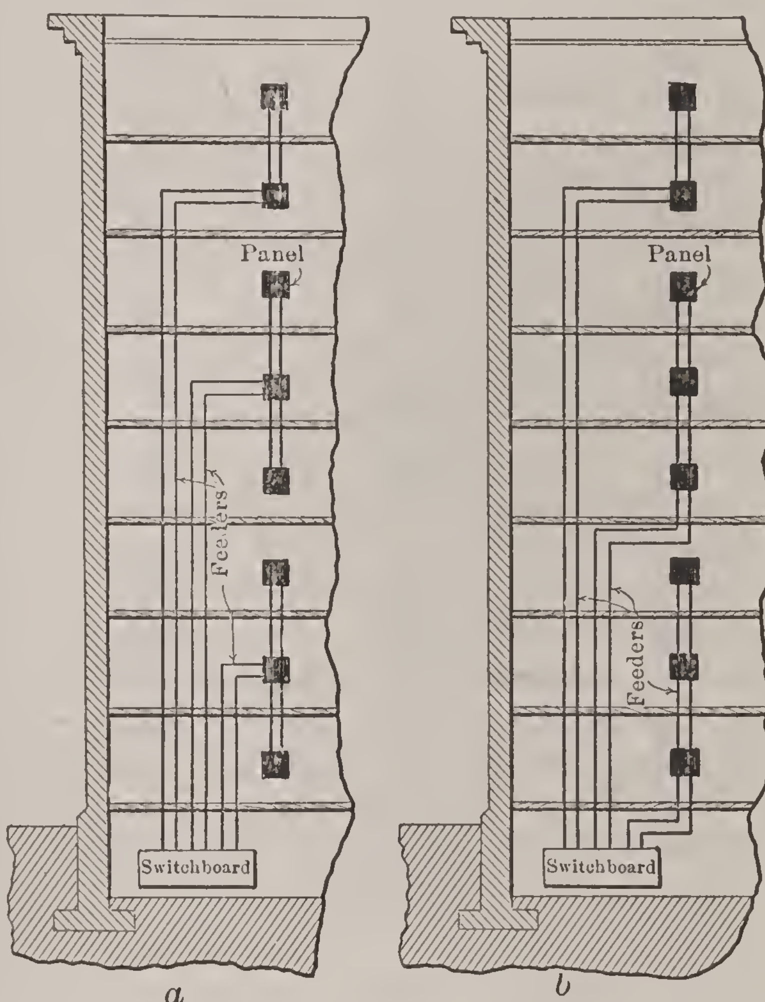


FIG. 221.—Feeder System for Office or Loft Building.
a. Centre feed. *b.* Bottom feed.

Fig. 223 is satisfactory and would generally be employed for the first floor of an office building or store and for each of the floors below ground. For the upper floors a vertical arrangement similar to Fig. 222 is preferable and is generally used. **Motor feeders and panel boards** are generally entirely separate from the lighting circuits, but the same general rules apply.

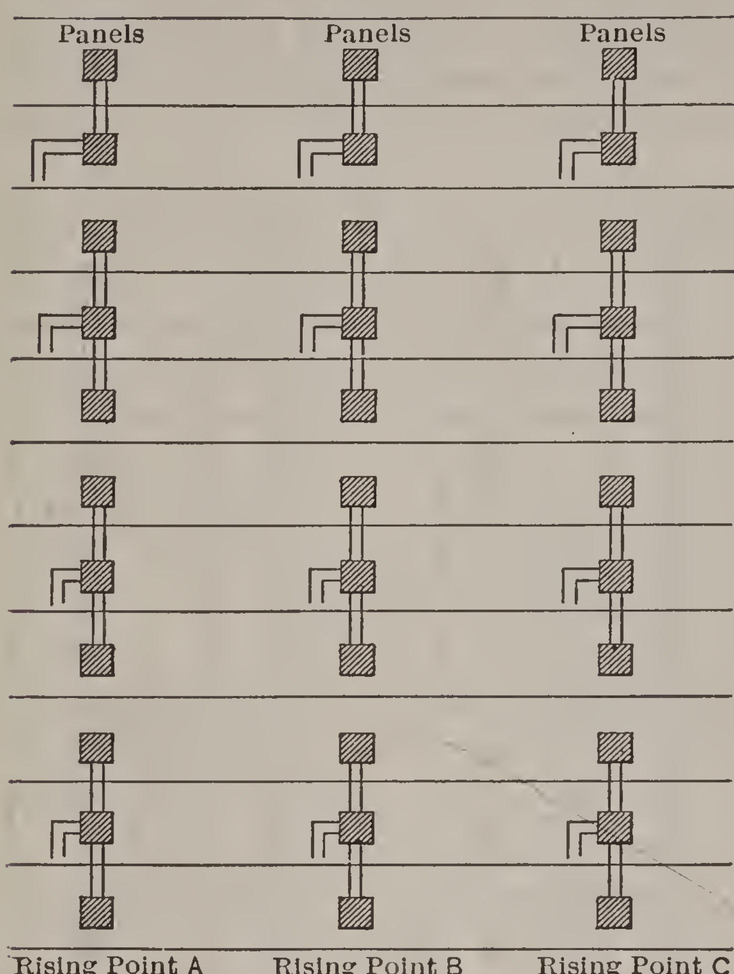


FIG. 222.—Feeder System for a Large Building.

300. Separate Control of Special Groups of Lamps. In large office and loft buildings it is desirable to control the hall lamps separately from the rest of the lighting load. These lamps are, therefore, supplied from independent feeders, thereby making it possible to cut off the supply from

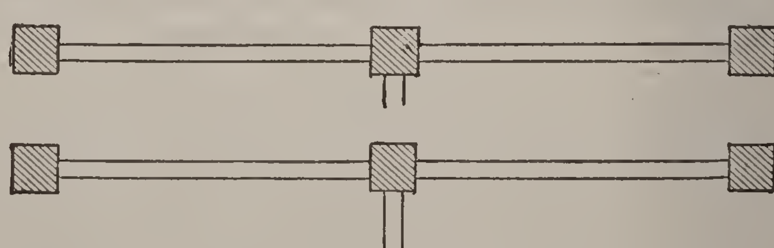


FIG. 223.—Method of Feeding Panel Boards.

the rooms when they are not occupied. In hotels, this arrangement is not necessary, as the feeders are left on continually.

In some cases the hall circuits are divided between two feeders, so that part of the lamps can be extinguished at night after the tenants have left the building. This arrangement is quite expensive and is used only in large buildings.

301. Control of Branch Circuits. For lighting service the branch circuits are sometimes controlled by switches in the panel boards. Knife switches are often used in such cases, but there is always danger of the operator receiving a shock. This arrangement is, therefore, suitable only when the control of the lamps is in skilled hands. Usually it is best to control the lamps by switches separate from the panel. These switches may be built into the panel board in such a way that they can be operated without exposing the panel board and fuses,* or they may be located at convenient places near the lamps. For office buildings and similar places, switches controlling the lamps should be located near the entrance to the room and on the lock side of the door. In large rooms, several switches may be used so that only the lamps required need be used at any time. In factories or stores, the switches may be located on columns or side walls and should be grouped together as much as possible. The switches should be about 4 ft. above the floor. **Push-button switches** are used for the best installations and **rotary snap switches** for cheaper equipments. **Single-pole switches** are allowed by the Code for branch circuits carrying not more than 660 watts, except in damp places, where double-pole switches must always be used (Rule 24*c*). For services, **double-pole switches** are required, and they are better for all work because they open both sides of the circuit. This divides the arc and causes less burning of the contacts. Double-pole switches are used generally for the better grade of work, especially in industrial plants, where the danger of grounds on the branch circuits is greater than for residences, etc. Three-way and four-way switches† are considered as single-pole switches. Nothing smaller than a 10-ampere switch should be used, because the 5-ampere size is not as substantial mechanically. In rooms open to the public and in public halls, switches operated by a key are frequently used. As a rule, lamps are seldom controlled individually by means of key sockets. Usually the fixtures, to be most effective, must be located so high that the sockets cannot be reached. Even

* See paragraph 293. † Paragraph 267.

where the sockets are within reach, it is best to provide switches to encourage the shutting off of the lamps when not needed. All **motors** must be provided with some form of starting device or controller which must be in sight of the motor in an accessible position (Rule 8*c*). A switch disconnecting all the wires of the branch circuit must also be provided, unless the starter is designed to open all wires. This switch must be in sight of the

Fig. 224.—Arrangement of Control Devices for a Motor.

motor. Each wire of the circuit must be fused. Fig. 224 shows an arrangement for a d.c. motor.

302. Special Circuits. For **hall lights,** it is convenient to control the lamps from two or more points. This can be done by using three-way switches (Fig. 225). It will be seen that the lamps may be lighted or extinguished from either switch, regardless of the position of the other. For control from three points, one four-way switch and two three-way switches are required. For each additional point of control, another four-way switch must be used, connected in the same manner as the four-way switch in the diagram. Large fixtures or "electroliers" are

frequently wired so that the lamps can be controlled independently in two or three groups. Electrolier switches are used for this purpose (Fig. 225). The combinations shown are two only of several different arrangements which can be secured by selecting the proper style of switch. For loft buildings, it is sometimes desired to light the hall lamps on only one or two floors at a time. This may be accomplished by the arrangement shown in Fig. 226. In residences, a **master switch** is sometimes

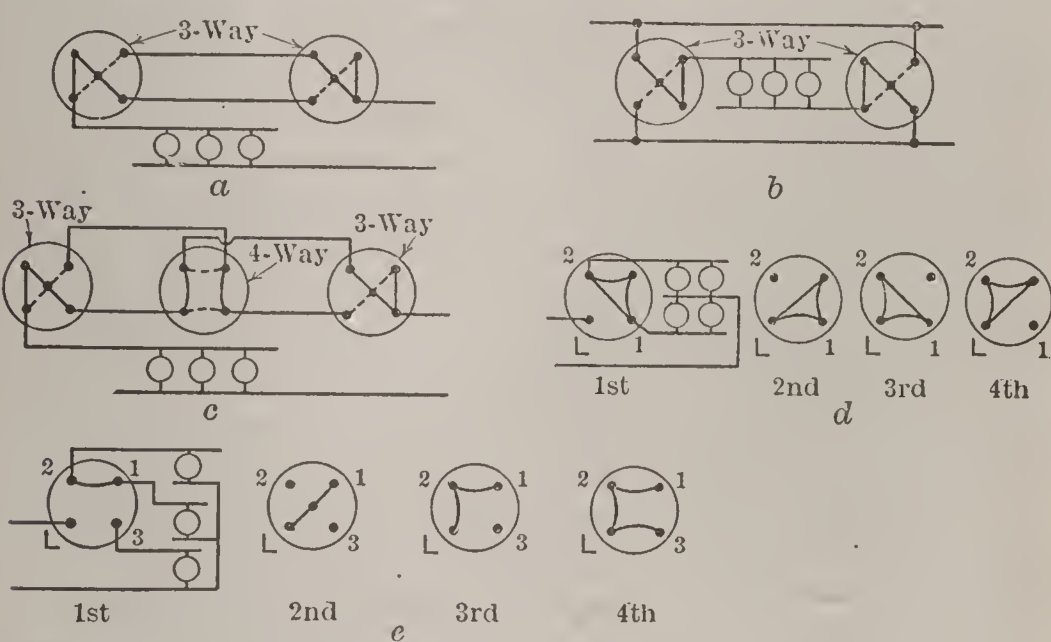


FIG. 225.—Diagrams for Special Lighting Circuits.

a. Use of 3-way switches for controlling lamps from two points. *b.* Same as (*a*) with different method of connection. *c.* Use of 3- and 4-way switches to control lamps from three places. For each additional place, a 4-way switch, connected the same as the middle switch must be used. *d.* Two-circuit electrolier switch. Arrangement gives: 1st, off; 2d, 1 on; 3d, 1 and 2 on; 4th, 2 on. *e.* Three-circuit electrolier switch. Arrangement gives: 1st, off; 2d, 1 on; 3d, 1 and 2 on; 4th, 1, 2 and 3 on. Other styles of electrolier switches can be obtained to give different combinations.

provided to control all or a part of the lamps in the house from one point (for example, the owner's bedroom), regardless of the position of the individual control switches. The arrangement shown in Figs. 227*a* and *b* is suitable only for a small number of lamps, since the master switch cannot be used to control more than 660 watts. One method of overcoming this difficulty is to use a special form of push-button switch.* The arrangement of connections is shown in Fig. 227*c*. The special push-button switch is used for the regular control of the lamps and

* Electrical World, March 11, 1916.

each of these switches is connected to a common wire leading to the master switch. By this means a portion of the lamps in each large fixture can be controlled from one point.

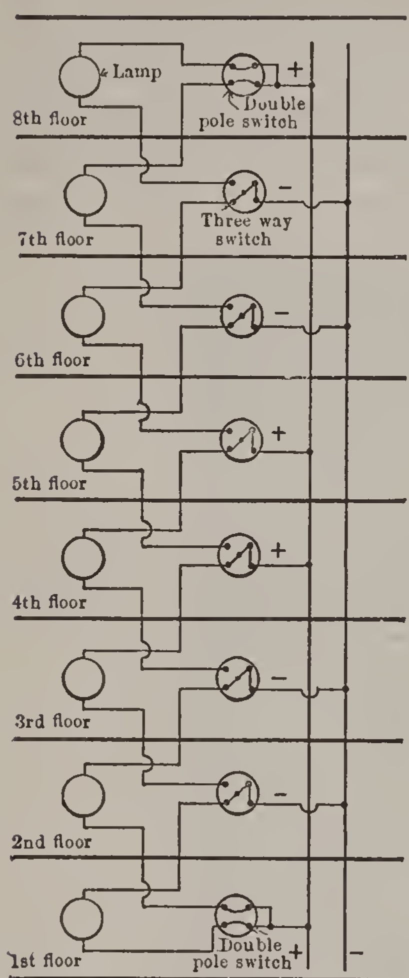


FIG. 226. — Connections for Hall Circuits in Tall Buildings.

A double-pole switch is provided at first and top floors, others have three-way switches. Closing switch on first floor lights the lamp on this floor and the floor above. Operating the switch on the second floor extinguishes the lamp on first floor and lights that on third floor. This is repeated on each floor up to the top. The arrangement can be used for any number of floors. The switch on each floor must be operated in passing.

303. Arrangement of Branch Circuits. Branch **lighting circuits** are almost always two wire. Such a circuit, which is protected by one set of fuses, cannot have more than 16 medium or 25 candelabra size sockets or receptacles, and the load must not exceed 660 watts (Rule 23*d*). It is better, however, to limit the number of sockets to 12. It will be seen that the Code allows the use of sixteen 40-watt lamps on one circuit, but as the lamps are usually larger than this, the number of sockets would generally be less. In counting the number of sockets, plug outlets must be included. Where the equivalent of No. 14 rubber-covered wire can be run directly into keyless sockets or receptacles 1320 watts and 32 sockets are allowed (Rule 23*d*). In arranging the branch circuits, an allowance should always be made for future additional load. The amount of this allowance varies, but as a general rule, for factory lighting, the load should be about 90 per cent, and for office buildings or stores from 80 to 90 per cent of the maximum load allowed on a branch. The larger allowance in the latter case is made to take care of the requirements of different tenants. It is, of course, important to have as much load as possible on a branch circuit (bearing in mind the above limitations), because each additional branch adds consider-

ably to the cost of the installation. The lamps on a branch circuit should be grouped together as much as possible to avoid very long circuits. Table 41 gives an indication of the limiting lengths of such circuits and will be found convenient when laying out branch wiring. For large public rooms, where it is important that the blowing of a feeder fuse shall not extinguish all of the lights in the room, the branch circuits are supplied from two or more feeders. As a rule, it is desirable to use only one size of wire for all branch circuits in a given installation and to so locate the panel boards that none of these circuits will exceed a suitable length. It is well to control the lamps nearest the windows separately from the others so that they can

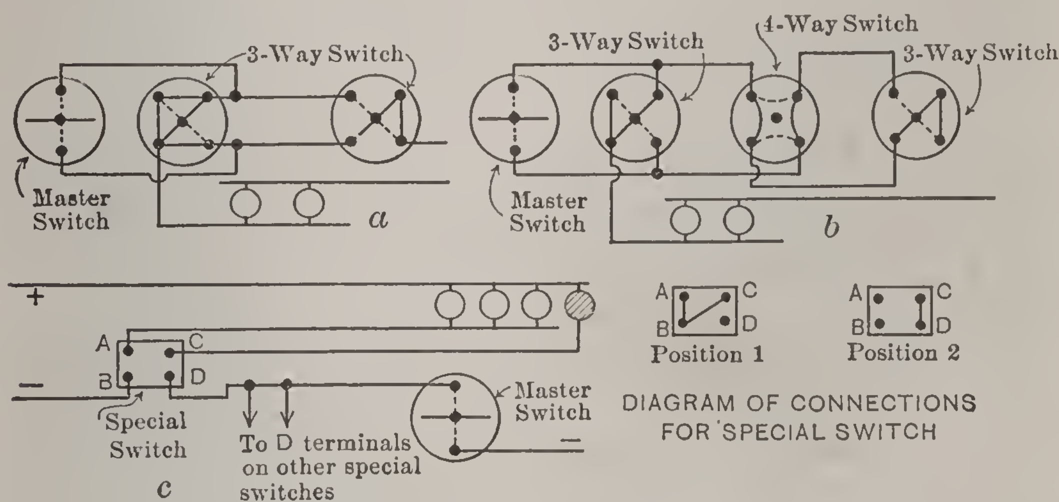


FIG. 227.—Master Switch Circuits.

a. With 3-way switches. *b*. With 3- and 4-way switches. *c*. With special push-button switches.

be extinguished when artificial light is needed only in the darker parts of the room. When branch circuits are supplied from a three-wire main it is important to divide the branches evenly between the two sides of the system, so that each panel board will have an evenly balanced load. Otherwise the neutral wires between panel boards will carry a balancing current, which will cause a disturbance in the voltage of the lamps, even if the total load on the system is so well balanced that no neutral current is drawn from the service. This means that three-wire panels and not two-wire should be used when three-wire mains and feeders are employed. For motor branches, a separate circuit is used for each machine, unless the motors are very small. Further details regarding motor branches are given in Chapters 19 and 20.

304. Location and Size of Panel Boards. For **office buildings,** the panel boards are located in the halls to avoid disturbing the tenants when fuses are to be replaced. In **stores and industrial establishments,** where large spaces must be supplied, the panels are located at some accessible place in the room on a side wall or column. In every case the panel should be located as nearly as possible at the centre of the load it supplies so that the branch circuits will all be nearly the same length. For **lighting panel boards** the exact location and the number used will depend upon the amount of load and the floor area. In a building of any considerable size it is necessary to have more than one panel board on a floor to avoid excessively long branch circuits. Reference to Table 41 shows that with No. 12 wire the load centre* of the branch can be about 110 feet away from the panel, so that the branch could feed lamps about 120 feet away in any direction. The distance between panels should, therefore, be not much over 250 ft. If No. 14 branch circuits are used the panels would have to be closer. As far as possible the panels on the different floors should be located in vertical lines to avoid offsets in the feeder circuits. It is much more difficult to conceal the large conduits required for feeders and mains in the floors of a building where horizontal runs are made than it is to conceal them in vertical runs, by means of wire shafts. Spare circuits should always be provided on the panels. In general there should be two spare circuits for a board having less than 10 circuits; four for 10 to 20 circuits and from six to eight for more than 20 circuits. For **motor panels** the same rules regarding location, etc., apply. The allowance of spare circuits must be made after a careful consideration of the possibility of additional motors being required. This would vary widely in different cases.

305. Location of Switchboards and Service Connections. If the building is supplied from a private plant, the feeder switchboard is naturally located in the engine room next to the generator panels. If the supply is from an outside service, there is usually a choice of locations for the switchboard. It should not be placed at one end of the building but, instead, should be near the centre, so as to make the lengths of the various feeders as nearly as possible the same. If this is done, the voltages at different points of the system can be made more nearly equal,

* See paragraph 318.

and there will be a considerable saving in the cost of the feeder system. Sometimes, when the private plant is a considerable distance from the building to be served, the electricity is transmitted in bulk, by a few large feeders, to a suitable distributing point in the building where the feeder switchboard can be located. Fig. 228 shows a typical switchboard where central station service is used. For small installations, there would be

FIG. 228.—Feeder Switchboard.

The large switches at the bottom are tie switches. (Krantz Mfg. Co.).

at the service point only the service switch and cutout required by the Code, together with the watt-hour meter for recording the total power consumed. From this point, a single feeder (or possibly one for lights and another for motors) would run to the first panel board. Fig. 229 shows the arrangement of a service for a residence. The location chosen for the service switchboard should be clean and as dry as possible, and provision should be

made to properly enclose the board to protect it from interference. There should be, at least, 3 ft. clear space between the ceiling and the top of the board. At least 18 in. free space must be provided between the wall and the apparatus on the back of the board, and it is better to allow more space than this, particularly if the fuses are on the back. To prevent the accumulation of rubbish back of the board, the panels should not extend down to the floor.

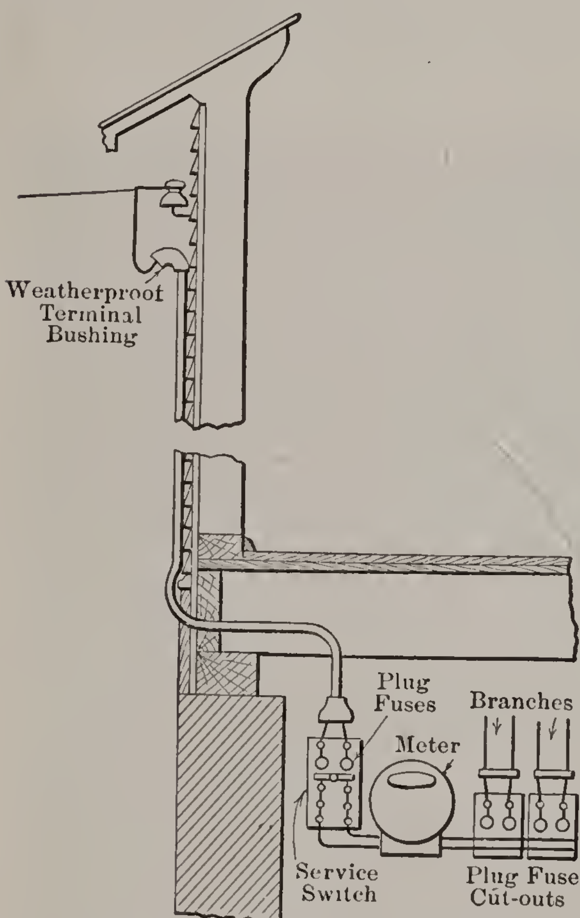


FIG. 229.—Service for a Residence.

306. Arrangement of Feeders and Mains. With the location of panel boards and switchboards settled, the feeder system can be planned. The considerations given in paragraph 299 will serve as a guide in doing this. In planning a feeder layout it is customary to sketch out the feeder system according to several arrangements and then to compare these with regard to first cost and convenience of arrangement. To do this, the panel boards are located on a riser diagram, which indicates the various floor levels and shows the approximate location of the panel boards. The feeder system is then sketched in and the loads calculated. Fig. 231 shows a riser diagram for a factory building.

307. Limitations in Size of Circuits. The methods of determining the sizes of the circuits are given in Chapters 19 and 20. There are, however, certain limitations in the size of these circuits which will have a bearing upon the arrangement used. As a rule, it is seldom desirable to use a cable larger than 1,000,000 cir. mils, especially for a.c. work at 60 cycles.* Where the circuits are to be run in conduit and all wires of a circuit must be placed

* See paragraph 323.

together, 500,000 cir. mils is about the limit in size because of the large conduits required. When horizontal runs are to be concealed in floors, a $2\frac{1}{2}$-in. conduit is about as large as can generally be used. This limits the size of conductors to 300,000 cir. mils where two or three wires are installed together. Vertical runs are concealed in wire shafts so that larger sizes may be used in such cases. In open wiring, there is not as much limitation in size, but usually it is desirable to so subdivide the load that the individual feeders need not be larger than 1,000,000 cir. mils. Generally they are considerably smaller.*

308. Grounding Circuits. Low-voltage circuits (i.e., 550 volts or less), for lighting or power service, must be grounded if supplied from a central station or a transformer having a primary voltage greater than 550 volts (Rule 15). For **three-wire systems,** either direct or alternating current, the neutral is grounded. For systems supplied from transformers having **no neutral** one side of the circuit must be grounded if the voltage between ground and any other wire is not over 150 volts. For higher voltages grounding is optional. The purpose of grounding is to prevent any chance of an excessive voltage occurring on a low-voltage system. With circuits fed from transformers there is always a chance that the insulation between the secondary and primary of the transformer may be weakened by lightning or other cause and a leakage occur (Fig. 230). If the low-voltage system is not grounded, a leak from the primary side would cause an excessive voltage between the wiring and ground, even if the insulation of the primary feeder system were perfect. If this occurred, a person touching a metal socket or a switch, especially if standing on a damp floor or in contact with water

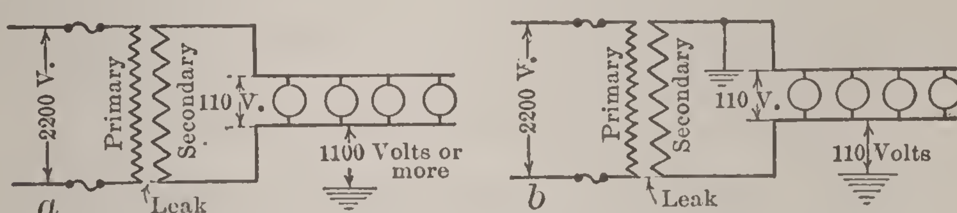


FIG. 230.—Grounding Low-voltage Circuits.
a. Not grounded. *b.* Grounded.

* Other reasons for reducing the size of a.c. circuits are given in paragraph 325.

piping (as in a bath room), would receive a severe and possibly a fatal shock, and fires would probably be started by arcs caused by the breaking down of the insulation. If the circuit is grounded, a leak in the transformer insulation would cause a current to flow to ground, the fuses would blow and thus disconnect the circuit. In this case, a person touching the fixtures would be protected. The **frames of motors and generators** must be grounded wherever feasible (Rule 8*a*). Where this is impracticable the motor may (by special permission) be placed on wooden base frames or a wooden floor which is clean and free from moisture.

CHAPTER 19

CALCULATION OF D.C. SYSTEMS

309. Factors which Affect the Size of a Circuit. All conductors used for electric wiring must be large enough to carry the current without overheating, and without an excessive loss of voltage and must also be strong enough mechanically to withstand any strains to which they may be subjected. The Code specifies definitely the largest current which a wire should carry,* but makes no requirements regarding voltage loss or drop. For mechanical reasons, no wire smaller than No. 14 B. & S. gauge is allowed, except in fixture wiring, where No. 18 is permitted.

Calculation of Load on a Circuit

310. Two-wire Branch Circuits. For **lamps or heaters,** the total current is found by dividing the total watts load on the branch circuit by the voltage. Where plug outlets for portable lamps are included these should be figured at not less than 40 watts each, and more if it is definitely known that they will be used for heavier loads. If **small motors** are also attached to the lighting circuit, the full-load current of these should be included. When the current taken by each outlet is known, the total current can be found by adding these currents together. **Large motors** (above one-fourth horsepower) must be supplied by individual branch circuits. The full-load current can be obtained from Table 21.

311. Determining Load on Lighting Panel Boards. For a **two-wire system,** the *actual load* on the panel is the sum of the currents required for the branch circuits as calculated in paragraph 310. The *maximum load* should also be estimated by allowing 600 watts per branch (or 1200 watts if double size circuits are used), including the spare circuits. For a **three-wire system,** the current for one of the outside terminals of the panel board is found by dividing the watts load connected to this ter-

* Table 36.

minal by the voltage between terminal and neutral. The current should be calculated for the side of the system having the greatest connected load, although in a properly designed system there should be very little difference between the two sides.

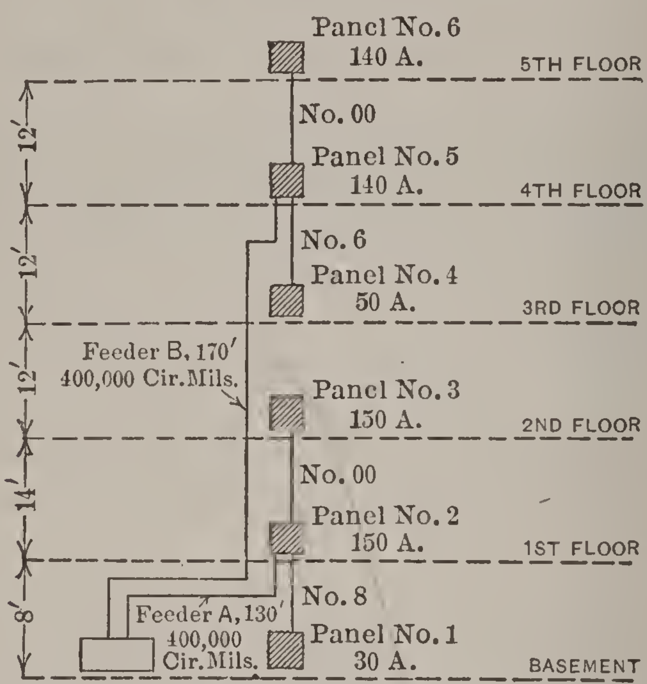


FIG. 231.—Riser Diagram for a Factory.

The actual loads and maximum loads should be figured as in a two-wire system.

Example 1. One floor of a factory is lighted by 108 units each rated at 100 watts. The units are arranged in 6 rows of 18 each giving two branch circuits per row or a total of 12 branches. (Double size circuits are used.) There are also three circuits for portables. An 18-branch panel board should be used. For a two-wire, 120-volt system we have:

Lamp load	$108 \times 100 = 10{,}800$ watts	
Portables	$9 \times 3 \times 40 =$	1,080
Total		11,880

The actual current is therefore $11{,}880 \div 120 = 99$ amperes. The maximum load is:

Lamp circuits	$12 \times 1200 = 14{,}400$ watts	
Portable circuits	$3 \times 600 =$	1,800
Spare circuits	$3 \times 600 =$	1,800
Total		18,000

The maximum current is $18{,}000 \div 120 = 150$ amperes.

Example 2. If a 240–120-volt, three-wire system is used, we have:

Lamp load	$54 \times 100 =$	5400 watts
Portables	$9 \times 2 \times 40 =$	720
Total for one side		6120

The actual current in the outside wire is $6120 \div 120 = 51$ amperes.
The maximum load is:

Lamp circuits	$6 \times 1200 =$	7200 watts
Portable circuits	$2 \times 600 =$	1200
Spare circuit	$1 \times 600 =$	600
Total for one side		9000

The maximum current is $9000 \div 120 = 75$ amperes.
The current in the neutral is practically zero and need not be calculated.

Where there are a number of panel boards, the loads should be tabulated as in paragraph 312.

312. Determining Load on Lighting Feeders or Mains. After the arrangement of feeders and mains has been made in accordance with one of the schemes described in Chapter 18, the load on each part of the circuit can be determined. This is computed from the loads on the panel boards which are supplied by the circuit. Both the actual load and the maximum load should be calculated. A riser diagram* is of assistance in determining these loads, as it can be seen at a glance just what panels are supplied by each circuit.

Example. Fig. 231 gives a riser diagram for the lighting feeders of a factory building and the tabulation below gives the loads on the panels. The feeder loads are as follows:

	Actual.	Maximum.
Feeder A:		
Panel No. 1	18 amperes	30 amperes
2	99	150
3	99	150
Total	216	330
Feeder B:		
Panel No. 4	30 amperes	50 amperes
5	90	140
6	90	140
Total	210	330

* See paragraph 306.

Loads on Panel Boards

For a two-wire, 120-volt system

Floor.	1 Panel No.	2 Circuits in Use.	3 Total Circuits Provided.	4 Load in Watts.	5 Actual Load, Amperes.	6 Maximum Load, Amperes.
Basement...	1	4	6	2,160	18	30
First floor...	2	15	18	11,880	99	150
Second floor..	3	15	18	11,880	99	150
Third floor..	4	8	10	3,600	30	50
Fourth floor.	5	12	16	10,800	90	140
Fifth floor...	6	12	16	10,800	90	140

A three-wire system would be calculated in a similar manner. For the example chosen, Feeder A would carry a maximum load of 165 amperes and an actual load of 111 amperes. For Feeder B the values are 165 amperes and 105 amperes.

313. Determining Load on Power Panel Boards. Since d.c. power circuits are almost always two-wire, only this system will be considered. The full-load current of each motor can be determined from the name plate on the machine or can be closely approximated from Table 21. In calculating the load on a power panel board, the maximum running load must be estimated as nearly as possible. Under usual conditions, the motors would not all carry full load at the same time, so that the maximum load would be less than the total full-load capacity of the motors connected to the panel. In estimating this maximum load, it is usual to employ a **demand factor** which is the ratio of the maximum load to the total full-load rating of the motors connected to the panel. This demand factor varies from about 0.40 to 1.25, depending upon the nature of the work and the number and size of the motors (see Table 38). The factor is larger where only a few motors are connected to the feeder. The connected load can be found by adding together the full-load currents of all the motors, including a proper allowance for any spare capacity in the panel board. Multiplying this connected load by the demand factor would give the maximum load on the panel board. This would be the maximum running current required for the entire panel board. Where one of the

motors is very much larger than the others, the starting conditions should also be considered. To do this, the maximum load on the panel when all motors but the largest are running should be found in the manner just described. To this should be added the starting current of the large motor. For shunt or compound motors, the starting current may be assumed to be 1.25 times the full-load current unless more definite information is available. For series motors, the starting current would be at least 1.50 times full-load current and might be greater than this for some types of service (see paragraph 315).

Example 1. Shunt motors, 120-volt system.
Running conditions:

1–5 hp. motor		40	amperes
1–3		24	
1–2.5		20	
2–1		17.6	
1–3	(spare)	24.	
Total		125.6	amperes

From Table 38, the demand factor is found to be about 0.65. Hence the maximum running current is:

$$125.6 \times 0.65 = 81.7 \text{ amperes.}$$

Example 2. If the panel which supplied the motors in Example 1 also had connected to it a 50-hp. motor, we would have to consider the starting conditions as follows:

Running load, six motors	81.7 amperes
Starting load 50-hp. motor, $356 \times 1.25 =$	443
Total	524.7 amperes

314. Determining Load on Power Feeders and Mains. A riser diagram of the power feeder system should be prepared to assist in determining the load. This diagram is similar to the lighting riser diagram already described. Where the motors are all of about the same size, the load on the feeder can be found by adding the maximum running loads of the panel boards. If, however, there is one very large motor, the load produced when this is started and all the others are running should be determined in the manner described in the previous paragraph. Where there are several panels supplied by one feeder, the load would actually be less than the sum of the loads of the different panels, because their maximums would not all occur at the same

time. Adding these loads, therefore, gives some spare capacity, which is generally desirable. It is always well, however, to calculate the maximum running load on the feeder by adding the full-load currents of all motors on the feeder and multiplying by the proper demand factor as found from Table 38. To this must be added a proper allowance for future load, which may be 25 per cent or more. The amount of this allowance depends a great deal upon whether the feeder is in a factory, where the load requirements may increase considerably due to the addition of more or larger machines, or in an office building where there is little chance for an increase in load.

Example 1. For a 230-volt system a feeder has the following connected load. All are for group drives:

1–25 hp. motor,	91 amperes
3–20	219
4–10	152
6– 5	120
Total	582 amperes

From Table 38, the demand factor is found to be about 0.70. Hence the maximum running current would be:

$$582 \times 0.70 = 407 \text{ amperes.}$$

Allowing 15 per cent for future additions, the current would be:

$$407 \times 1.15 = 469 \text{ amperes.}$$

315. Determining Size of Branch Circuits and Fusing. The smallest branch circuit allowed is No. 14, but for long runs, especially for motors, it is better practice to use No. 12. For **lighting circuits,** the branch loads are limited to 660 watts, or in special cases 1320 watts.* The circuits may be fused as follows:

FUSES FOR BRANCH LIGHTING CIRCUITS

Voltage.	Size of Fuse.	
	660-watt Branch, Amperes.	1320-watt Branch, Amperes.
125 volts or less...........	10	20
126 to 250 volts...........	5	10

* See paragraph 303.

Each **arc lamp circuit** must have a carrying capacity and be fused for a current at least 1.50 times the rated current of the lamp to allow for the starting conditions. Branch circuits for **motors** must have a carrying capacity at least 25 per cent greater than the full-load rated current (Rule 8*b*). The size of wire is determined from column A or B of Table 36, depending upon the kind of wire used. When branch circuits are fused for a capacity 25 per cent greater than the full-load current of the motor, this will allow momentary overloads of 50 per cent without blowing the fuses, because of their time element.* This will meet the usual industrial conditions. In some cases very severe momentary overloads might require the use of larger wires. The rule just given applies to motors for continuous duty.† Table 39 gives the proper size of fuses for motors. Crane and hoist motors should be fused for not less than 1.50 times full-load current. Motors for operating valves, moving planer cross-rails, etc., should be fused for 2.0 times full-load current.

Example. A 10-hp., 230-volt motor operating a hoist would require a current of $1.50 \times 38 = 57$ amperes. This would require a No. 5 rubber-covered wire.

A fuse must be used in each wire of a branch circuit. When a branch circuit is protected by a circuit breaker, it must not be set more than 30 per cent above the rating of the wire (Table 36), unless fuses are also provided.

316. Determining Size of Feeders or Mains and Fusing. In the case of **lighting circuits,** the feeders or mains should be of sufficient size to carry the *maximum* load as calculated in paragraph 312. Table 36 is used in selecting the size. Feeders or mains should be fused to the full current capacity allowed by this table even if the normal load is considerably less than this, as occurs when the size of the circuit is increased to reduce the voltage drop. By fusing in this manner there is less chance of the fuse blowing because of overloads. When circuit breakers are provided, they should be large enough to carry the maximum load on the circuit. Since they can always be set for currents about 60 per cent above their rating, this allows sufficient margin, in general, for possible momentary overload. The **neutral wire** of a three-wire circuit must be of sufficient

* See paragraph 282. † See paragraph 165.

capacity to carry the entire load of one side of the system (Rule 16*h*). Generally the neutral wire is made the same size as the outside wires, but if these are increased in size to reduce the drop, the Code does not require an increase in the size of the neutral. If the neutral is grounded,* the fuse in the neutral wire must be omitted (Rule 23*b*), except in two-wire branch circuits. This is done to prevent an excessive voltage on the lamps caused by a neutral fuse blowing† and also to ensure that the entire system shall always be grounded while in use. For **motors,** the load based on running conditions, as determined in paragraph 314, can be used as a basis for the size of feeder. The exceptions to this are the cases where there is one very large motor, or where the feeder supplies cranes or similar apparatus. In such cases, the starting loads must be considered.

Example 1. For the example in paragraph 312, Feeder A has an estimated maximum load of 330 amperes and hence should be at least 400,000 c.m., if rubber insulation is used. This wire is rated at 325 amperes and would have to be fused for that current. Since the actual load is only 216 amperes there is still plenty of margin allowed for extensions. Feeder B would be the same size.

Example 2. For a three-wire system the feeders would be No. 000 with neutrals of the same size. The fuses would be 175-ampere size. For motor circuits the size of feeders and mains is based upon the current required for the maximum running load, except when the starting loads are heavy.

Example 3. For Example 1, paragraph 313, the current is 81.7 amperes. Hence the size of circuit to supply these motors would be No. 3 if rubber insulation is used.

Example 4. For Example 2, paragraph 313, the current is 524.7 amperes. This would require a 750,000 c.m. cable.

Calculation of Voltage Loss

317. Increasing Size of Wire to Reduce Loss. The sizes of circuits determined by the aid of Table 36, in a manner previously described, are sufficient to carry the load without overheating. It frequently happens, however, with long circuits that the voltage loss or drop is excessive under these conditions. The voltage drop should therefore be calculated and the size of wire increased, if necessary. In Table 40, are given values of maximum voltage drop, which should not be exceeded. These values apply particularly to industrial work. Where there are no mains, this part of the drop may be included in the feeder

* See paragraph 308. † See paragraph 215.

drop. Incandescent lamps are very sensitive to voltage changes and therefore the drop must be kept small. Power circuits can have a greater drop, but it should not be too large, particularly with induction motors, as they do not operate satisfactorily at voltages greatly below normal.*

318. Calculation of Voltage Drop. For a **two-wire** d.c. circuit, the voltage drop or loss can be calculated from the formula:

$$\text{Volts drop} = \frac{21.4 \times \text{distance in feet} \times \text{amperes}}{\text{cir. mils}} \quad . \quad . \quad . \quad (1)$$

The size of wire can be calculated, if the required voltage drop is known, by the formula:

$$\text{Cir. mils} = \frac{21.4 \times \text{distance in feet} \times \text{amperes}}{\text{volts drop}} \quad . \quad . \quad . \quad (2)$$

The distance is the length of run from the supply point to the load. If the load is concentrated at one point, it is the total length of the circuit or one-half the total length of wire used.

Example 1. Calculate the voltage drop on a two-wire, No. 00 feeder (133,100 c.m.), 150 ft. long carrying 50 amperes.

$$\text{Voltage drop} = \frac{21.4 \times 150 \times 50}{133{,}100}$$
$$= 1.2 \text{ volts.}$$

Example 2. Required, the size of wire to carry 50 amperes a distance of 150 ft. with a drop of 1.5 volts.

$$\text{Cir. mils} = \frac{21.4 \times 150 \times 50}{1.5}$$
$$= 107{,}000 \text{ c.m.}$$

Hence No. 0 is the nearest size.

While any d.c., two-wire circuit can be calculated by means of these formulas, it is generally more convenient to use some form of chart. The chart† shown in Fig. 232 will be found useful for this purpose. If it is desired to find the drop for the feeder already calculated, start at 50 amperes on the lower left-hand side and follow vertically until this line crosses that for 00 wire;

* See paragraph 169.

† This chart is a modification of one devised by R. W. Stovel and N. A. Carle (see Electric Journal, June, 1908), and was published by the author in Power, May 18, 1915. It is based on the formulas given above.

then pass horizontally to the right to the line marked 150 ft. and follow down vertically and read 1.2 volts. To determine the size of wire as in the second problem, start with 1.5 volts at the lower right-hand side and follow up vertically to the 150-ft. line; then horizontally to the left to the line for 50 amperes, which also crosses the No. 0 line at this point. For a **three-wire system** the chart requires some modifications. With a balanced system, all the drop occurs in the outside wires, and for the lamps on one side we have to take into account the drop in only one wire. Hence, if we use the current in the outside wire, and a distance equal to the length of run as in a two-wire system, then the voltage drop determined from the chart should be divided by two.

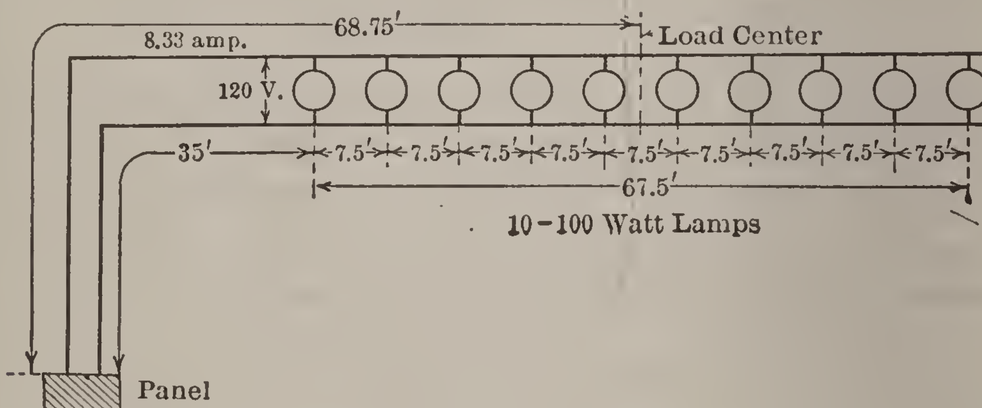


FIG. 233.—Method of Finding the Load Centre.
Units all same size and uniformly spaced.

Example 3. A three-wire system is carrying 50 amperes on each side and the length of run is 150 ft. Using the chart, it is found that for a two-wire circuit the drop is 1.2 volts. Hence the drop on one side of the three-wire system is 0.6 volt.

Example 4. It is required to find the wire size for a three-wire circuit to carry the same load as in Example 2. There would be a load of 25 amperes on each side of the system, and with a voltage loss in *each* of the outside wires of 1.5 volts, the loss at the lamps would be the same as in Example 2. Using the chart, we find the size of a two-wire circuit to carry 25 *amperes with* 3.0 *volts drop*. This requires a No. 6 wire. Hence this No. 6, three-wire circuit transmits the same load as the No. 0, two-wire circuit. The drop in voltage across the lamps is the same, being 0.75 volt for each of the wires of the two-wire system and 1.5 and 0 volts drop for the outside wire and neutral, to which the lamps are connected, in the three-wire system.

Where the load is distributed along the circuit, the distance used in calculating the drop is *not* the distance to the end of the run

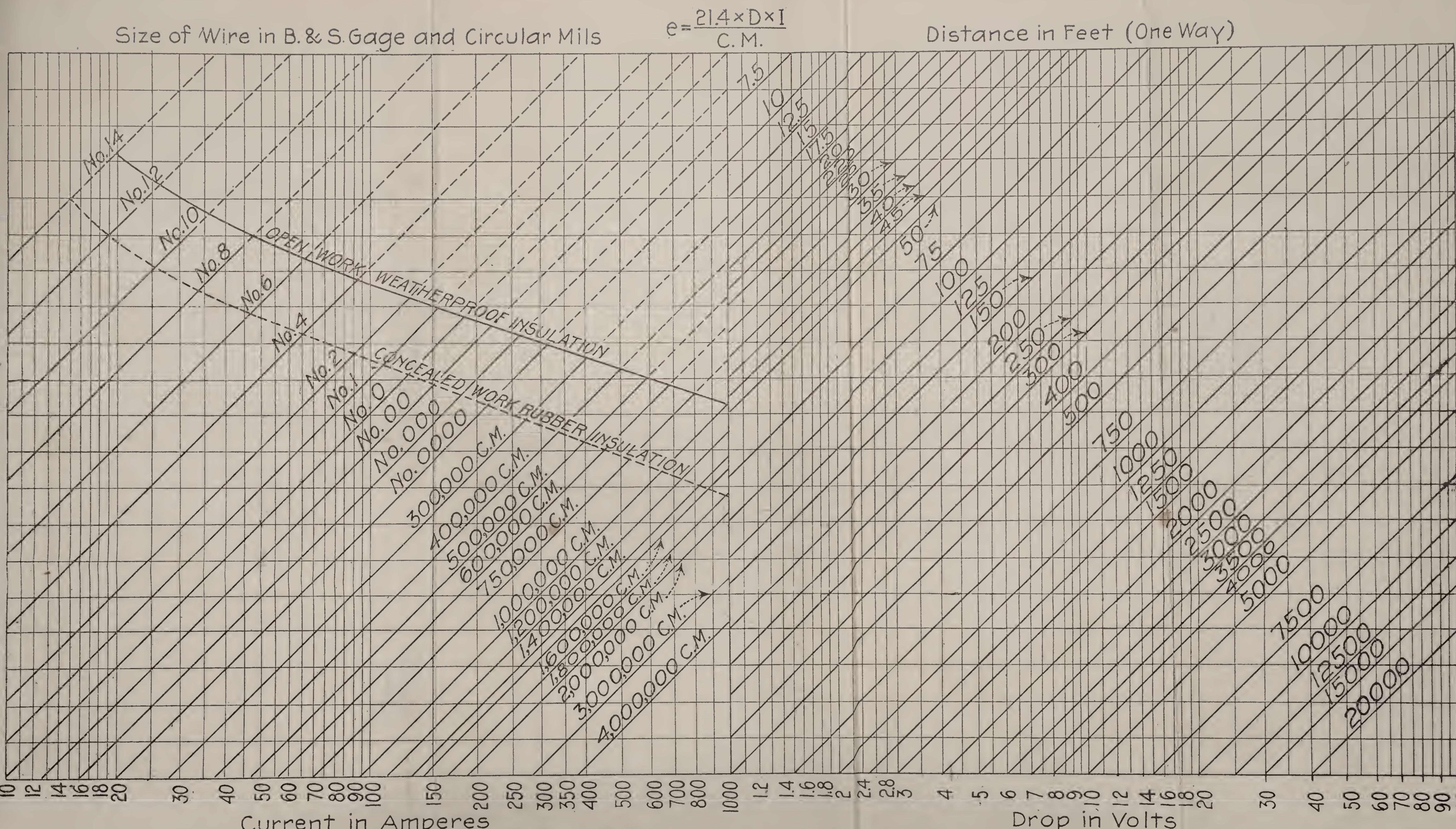


FIG. 232.—Stovel-Carle Wiring Chart for Direct Current Circuits. (Courtesy of *Power*.)

(To face page 318).

but to the load centre. The method of finding the load centre can be explained by examples:

Example 5. There are ten 100-watt, 120-volt lamps spaced as shown in Fig. 233. The total load is $1000 \div 120 = 8.33$ amperes. The distance between end lamps is 67.5 ft. Since the lamps are all the same size and evenly spaced, the load can be considered as concentrated at a point halfway between the fifth and sixth lamps. The total distance is therefore $35 + \frac{67.5}{2} = 68$ ft. 9 in. This is the position of the load centre. With a No. 12 wire the drop is 1.88 volts.

Example 6. With the lamp loads unevenly spaced and of different sizes (Fig. 234), the load centre must be found by multiplying each load by its distance from the panel board. The sum of these products

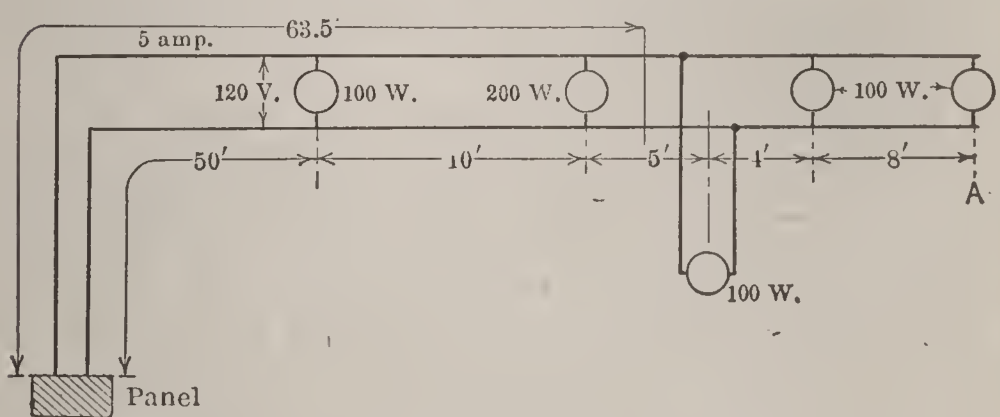


FIG. 234.—Method of Finding the Load Centre.
Units different sizes and unevenly spaced.

divided by the total load will give the distance of the load centre. Thus for Fig. 234 we would have:

$$\begin{aligned} 50 \times 100 &= 5{,}000 \\ 60 \times 200 &= 12{,}000 \\ 65 \times 100 &= 6{,}500 \\ 69 \times 100 &= 6{,}900 \\ 77 \times 100 &= 7{,}700 \\ \hline & \ 38{,}100 \end{aligned}$$

Total load = 600 watts.

Distance of load centre $= 38{,}100 \div 600 = 63.5$ ft.
At 120 volts the current is 5 amperes. With No. 14 wire, the drop would be 1.65 volts. The drop thus calculated is that to the furthest lamp (*A* in Fig. 234). The drop to the other lamps which are nearer the panel board would be somewhat less. It will be noted that the load on the tap was calculated as if it were located on the main run. If the tap circuit is very long, the drop on this would

have to be added to the drop on the main run to the point where the tap is connected, but usually the drop in the tap can be neglected. If the loads are given in amperes, the same method of finding the load centre can be employed.

319. Calculating Drop on Branch Circuits. For **lighting circuits,** it is necessary to calculate the drop on a few of the longer runs only. If the distance to the load centre is less than the distances given in Table 41, there is no need of checking the drop. For **motor circuits,** the branch usually carries a single motor. The drop should be calculated for the *full-load currents,* using the formula or chart. In the case of motor branch circuits, it is not generally necessary to calculate the drop for all the branches. Usually the size of wire which must be used to carry the required current is large enough to keep the drop below the values specified in Table 40.

320. Calculating Drop on Feeders and Mains. After the loads and smallest size of wire have been calculated,* the drop should be determined. For a feeder which supplies several panel boards, the load centre could be found and the drop to the farthest panel board determined thereby. This would serve as a check, but it is usually better to find the drop to each panel board on the feeder. To do this, the drop for each part of the circuit is found by means of the formula or chart. The total drop to any point can then be found by adding the drop on each part. For **lighting circuits,** the load used in calculating the drop is the *actual load* and not the maximum load.†

Example. Taking the loads used in Example 1, paragraph 312, and the sizes of feeders calculated in paragraph 316, determine the drop, if a two-wire, 120-volt system is used. Feeder B (400,000 c.m.) carries 210 amperes, 170 feet. This would give a drop of 1.91 volts. Next, the drop on the mains should be calculated. The main feeding panel No. 6 must be at least No. 00 (for 140 amperes). The length is only 12 ft. and the drop is 0.17 volt. The total drop to panel No. 6 is therefore 2.08 volts. The allowable drop is 5.2 volts, hence the sizes are large enough. Feeder A is only 130 ft. long and carries 216 amperes. The drop is 1.5 volts, which is satisfactory.

For **motors,** the actual load with the motors running should be used to calculate the drop. Thus, in Example (1) paragraph 313, the drop should be figured for a current of 81.7 amperes. The drop when a motor is starting may be greater than this, but as it only lasts for a short time the larger drop is not serious.

* See paragraph 316. † See paragraph 312.

CHAPTER 20

CALCULATION OF A.C. SYSTEMS

321. In a.c. circuits, due to the reversals of the current, phenomena occur which are not present in d.c. systems. Of these, the only ones which are important in interior wiring calculations are self-induction and skin effect.

322. Self-Induction. A wire carrying alternating current is surrounded by a magnetic field which is also alternating. This field generates in the wire a voltage which opposes the flow of current through the wire. In an a.c. circuit, therefore, there is a drop due to the resistance of the wire (the same as d.c. drop), and an additional drop due to the self-induction. The amount of inductive drop depends upon the **spacing of the wires,** the frequency and the size of the wire. If the wires forming a circuit are close together, as in a multiple cable or when installed in the same conduit, the field around each wire is almost neutralized by the current in the other wires and the inductive drop is small. On the other hand, exposed wiring run on cleats and having a separation of several inches may sometimes have an inductive drop double the d.c. drop. The **frequency** affects the inductive drop, because faster reversals of the field produces a higher self-induced voltage. For 60 cycles, the inductive drop is 2.4 times the drop for 25 cycles. Where the **power factor** of the load is 1.0 (as for incandescent lamps or heaters), the inductive effect is usually not important. For arc lamps or motors however, it generally cannot be neglected.

323. Skin Effect. This term is given to the apparent increase in the resistance of a conductor when carrying alternating current. The central portion of a wire is surrounded by a magnetic field which is stronger than the field around the outside portion. Hence the inductive voltage produced in the central portion is higher, giving a greater opposition to the flow of the current through the centre. As a result, the current is crowded towards the surface of the conductor, to such an extent that the centre,

in the case of large conductors, carries practically no current. The wire acts as if the cross-sectional area had been reduced by taking out the central part; in other words, the apparent resistance is increased. Skin effect increases with the frequency and the size of wire. Table 42 can be used to determine skin effect. It will be seen that this is negligible for wires smaller than 300,000 cir. mils on 60 cycles and 750,000 cir. mils on 25 cycles. The skin effect for iron conductors, such as steel rails, etc., is very much greater. It is apparent that, due to skin effect, a large cable carrying alternating current would run somewhat warmer than when carrying the same amount of direct current. Although the Code makes no difference in the current rating,* this point should be remembered when very large cables are to be used for carrying alternating current.

324. Power Factor. In a.c. circuits, we have to consider two quantities, the real power (expressed in watts or kilowatts), and the apparent power (expressed in volt-amperes or kilovolt-amperes). The **apparent power** is the product of the volts and amperes. The **real power** may equal the apparent power, but in many cases it is less. It can never be greater. The real power is measured by an instrument called a wattmeter. The ratio: Real power divided by the apparent power gives the power factor. Hence, we can say that the power factor is the quantity by which the apparent power is multiplied to obtain the real power. The usual values of the power factor are given in Table 43. All of these, except the first are "lagging" power factors. "Leading" power factors may be produced by synchronous motors, but they will not be considered here. The effect of a lagging power factor is, in general, to increase the total voltage drop in an a.c. circuit.

325. Grouping of Conductors. With direct current, it makes no difference (as far as drop is concerned) whether all the wires of a circuit are in the same conduit or are separated. A.c. circuits, however, when installed in iron conduit, must have all the wires of a circuit in the same conduit. If separated, the magnetic fields around the wires are not neutralized† and, in fact, they are greatly increased by the presence of the iron. As a result, the inductive drop will be very high and the conduit will heat if the wire is carrying a large current. If the current is so great as to require more than one wire for each lead

* See Table 36. † See paragraph 322.

of the circuit, and it is not feasible to put them all in one conduit, because of the large size required, the leads should be divided into two or more groups, each containing all the poles of the circuit. The proper arrangement for a three-phase circuit is shown in Fig. 235, where the leads of the three phases are 1, 2 and 3, respectively, 1*a* and 1*b* being of the same polarity. This rule applies for all types of a.c. systems except the two-phase, four-wire, which is practically the same as two single-phase circuits, so that phases *A* and *B* may be run in separate conduits. The relative amount of inductive drop increases rapidly as the size of conductor is increased. As a rule, wires larger than 300,000 cir. mils should be avoided, except where the wires are in conduit, when a size of 500,000 cir. mils or larger may be used. Circuits requiring a greater capacity than this can best be made up of two or more wires in parallel.

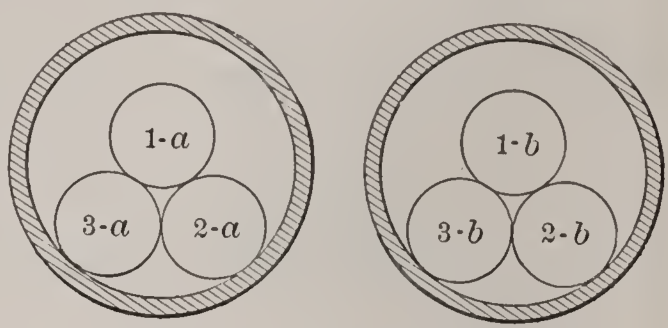


FIG. 235.—Arrangement of Wires in Conduit.

Example. A 500,000 cir. mil feeder (spacing 6 ins.) carrying a load of 300 amperes at 60 cycles a distance of 500 ft. has a drop of 18.5 volts with a power factor of 0.8. It is required to find the size of wire, to give the same drop, with the load divided between two feeders. By calculation, it is found that a No. 00 (133,000 cir. mils) circuit carrying 150 amperes gives a drop of 17.2 volts. Hence two of these could carry as much load as the single 500,000 cir. mil feeder, and the drop would be somewhat less. Therefore the load can be transmitted by two circuits totaling 266,000 cir. mils with practically the same voltage drop as a single 500,000 cir. mil circuit. The saving in copper is partly offset by the additional cost of running two circuits.

If two feeders are used, they should always be of the same size. Thus, in the example given, if a No. 000 (168,000 cir. mils), cable and a No. 0 (106,000 cir. mils) cable were used, the smaller wire would be overloaded, although the total amount of copper is 274,000 cir. mils.

Calculation of Load on a Circuit

326. As in d.c. circuits, both the maximum and actual loads on lighting panel boards, feeders and mains should be determined. For motors, running and starting conditions must be figured, using demand factors as explained in paragraph 313.

327. Single-phase Circuits. For **incandescent lamps or heaters on two-wire systems,** the load is found in the same way as for direct current.* For **arc lamps,** the total current can be found by adding together the currents required for the various lamps. If the rating is given in watts the current is found by dividing the watts by the voltage and the power factor (see Table 43).

Example 1. Find the current required for ten arc lamps each taking 500 watts at 110 volts.

$$\text{Current} = \frac{10 \times 500}{110 \times 0.60} = 75.7 \text{ amperes.}$$

Where loads of different power factors (for example arc and incandescent lamps) are on the same circuit the total current is slightly less than the sum of the currents required by the two kinds of load. In general, however, this difference is so slight that it can be neglected.†

Example 2. For 10 flame-arc lamps taking 7.5 amperes each and 15 Cooper Hewitt lamps requiring 3.8 amperes, we have

Flame arcs 10 × 7.5	= 75 amperes
Cooper Hewitt lamps 15 × 3.8	= 57
Total	132 amperes

Actually, since the power factors are different, the total current is less than 132 amperes. It is, in fact, 130 amperes.‡

The full-load current of **single-phase motors** can be found by doubling the values given in Table 23. The starting current may be taken as 2 times the full-load current. The total running current and starting current can be calculated by the methods given in paragraph 313.

* See paragraph 310.

† See paragraph 330 for method of calculation.

‡ See paragraph 330.

Example 3. 110-volt, single-phase motors.
Running conditions:

1–5 hp. motor		46.4 amperes
1–3		28.8
1–2.5		25.0
2–1		22.4
1–3	(spare)	28.8
Total		151.4 amperes

Running current $151.4 \times 0.65 = 98.5$ amperes.

Single-phase, three-wire circuits are arranged the same as d.c., three-wire circuits and the calculations are the same except for the modifications due to having different power factors.

328. Three-phase Circuits. Two arrangements of lamps or other single-phase loads are possible (Figs. 113 and 114). The branch circuits supplying the lamps would be two-wire and would be connected to the three-phase feeders through three-phase panel boards in such a manner as to distribute the load as evenly as possible on the three phases. The total current taken by the branch circuits connected across one phase can be calculated as if they were on a single-phase system.* When a **three-phase, three-wire system** is used it is apparent that there are two of these single-phase groups connected to each of the line wires. If the current required by all three groups is the same (balanced load), the current in each of the three-phase line wires is 1.73 times the current taken by one of the groups.

Example 1. Sixty 100-watt, 120-volt lamps are connected to a three-phase, three-wire feeder. The current taken by each phase is

$$\frac{20 \times 100}{120} = 16.7 \text{ amperes.}$$

The current in each line wire is $16.7 \times 1.73 = 28.9$ amperes.

Example 2. With the same load as in Example 1, paragraph 311, we have for each phase:

Lamp load 36×100	=	3600 watts
Portables 9×40	=	360
Total		3960 watts

* By the methods given in paragraph 327.

Single-phase current $3960 \div 120 = 33$ amperes.
Actual current in three-phase line $1.73 \times 33 = 57$ amperes.
For maximum load conditions we have:

Lamp circuits 4×1200	$= 4800$	watts
Portable circuit 1×600	$= 600$	
Spare circuit 1×600	$= 600$	
Total	6000	watts

Single-phase current $6000 \div 120 = 50$ amperes.
Maximum current in three-phase line $1.73 \times 50 = 86.5$ amperes.

If the loads on the three phases are not equal, the system is **unbalanced** and the currents in the three line wires are not alike. The current in any line may be found as follows: Divide one of the loads by 2 and add the result to the other load connected to the same line wire. Call this result A. Multiply the first load by 0.866 and call this B. Square A and B, add them and extract the square root. This is the current in the line.

Example 3. The feeder in Fig. 113*b* has loads of 20, 10 and 20 amperes connected across the three phases. The total load for line 1 is a combination of 20 amperes and 10 amperes. Hence,

$$A = 20 + 10 \div 2 = 25$$
$$B = 10 \times 0.866 = 8.66$$

The current in 1 is therefore:— $\sqrt{(25)^2 + (8.66)^2} = 26.5$ amperes.

The load for line 2 is a combination of 20 amperes and 20 amperes. Hence,

$$A = 20 + 20 \div 2 = 30$$
$$B = 20 \times 0.866 = 17.32$$

The current in 2 is therefore:— $\sqrt{(30)^2 + (17.32)^2} = 34.6$ amperes.

The load for line 3 is a combination of 10 amperes and 20 amperes. Hence,

$$A = 10 + 20 \div 2 = 20$$
$$B = 20 \times 0.866 = 17.32$$

The current in 3 is therefore:— $\sqrt{(20)^2 + (17.32)^2} = 26.5$ amperes.

This method is correct only when the loads on the different phases all have the same power factor. When this power factor is different, the method gives only approximate results for the reasons stated in paragraph 330. When a **three-phase, four-wire system** is used, the lamps are connected between the line wires and neutral (Fig. 114). The current in each line wire is the total current required for the load connected to that wire. If the loads are equal (balanced), the currents in the line wires

will be alike, and no current will flow in the neutral. With unequal loads, there will be a neutral current. When there is a load on one phase only the neutral must carry the same current as the line wire. Hence, all three line wires and the neutral are usually made the same size. **Motors** would be connected to the three line wires for either of the three-phase systems and would have no connection with the neutral (Figs. 113 and 114). Table 22 can be used to determine the full-load current of each motor. The running and starting conditions should be calculated for motor circuits as explained in paragraph 313. The starting current of squirrel-cage motors can be taken as 2 times the full-load current and for slip-ring motors 1.25 times the full-load current. The actual current is more than this, but it lasts for such a short time that the overload capacity of the fuses will prevent their blowing.

Example 4. For three-phase, squirrel-cage motors (220-volt) we have, using Table 22:

1–5 hp. motor		13.4 amperes
1–3		8.2
1–2.5		7.3
2–1		6.4
1–3	(spare)	8.2
Total		43.5 amperes

Running load $43.5 \times 0.65 = 28.3$ amperes.

Example 5. If in addition there was a 50-hp. motor, we should have to consider the starting conditions as follows:

Running load, six motors	= 28.3 amperes
Starting load 50-hp. motor 122×2	= 244.0
Total	= 272.3 amperes

329. Two-phase Circuits. Lamps or other single-phase loads would be distributed on the two phases. A **four-wire, two-phase system** (Fig. 115) can be treated like two single-phase systems and calculated in the same manner. A **three-wire, two-phase system** (Fig. 116) would have the lamps connected between the outside wires and the common wire. The current in an outside wire is the total current required by the load connected to that wire. The current in the common wire, for a **balanced load,** is found by multiplying the current in either line wire by 1.41.

For an **unbalanced load,** the current in the common wire is found by squaring the value of current in each outside wire, adding these results and extracting the square root. Where the loads on the two sides have different power factors, these methods give only approximate results.

Example 1. Four-wire system. Sixty 100-watt, 120-volt lamps. With equal loads on the two phases there would be

$$\frac{30 \times 100}{120} = 25 \text{ amperes}$$

in each of the four wires.

Example 2. Three-wire system (Fig. 116*a*), balanced load.

Current in each outside wire = 30 amperes.
Current in common wire $30 \times 1.41 = 42.3$ amperes.

Example 3. Three-wire system (Fig. 116*b*), unbalanced load.

Current in line 1 = 15 amperes
Current in line 2 = 30
Current in common wire $-\sqrt{(15)^2+(30)^2} = 33.5$ amperes.

Motors are connected to all of the wires of the circuit. Table 23 gives the currents required for two-phase motors. Both the running and starting conditions should be calculated as explained in paragraph 313. The starting current can be taken as the same percentage of full-load as for three-phase motors; i.e., 2 times full-load current for squirrel-cage motors and 1.25 times full-load current for slip-ring motors.

Example 4. Four-wire, 220-volt system, squirrel-cage motors:

1–5 hp. motor		11.6 amperes
1–3		7.2
1–2.5		6.3
2–1		5.6
1–3	(spare)	7.2
Total		37.9 amperes

Running load $37.9 \times 0.65 = 24.6$ amperes.

Example 5. If in addition there was a 50-hp. motor, we should have to consider the starting conditions as follows:

Running load, six motors	= 24.6 amperes
Starting load 50 hp.-motor 105×2	= 210.0
Total	= 234.6 amperes

Example 6. For a three-wire, 220-volt system, Example 4 above:

Current in each outside wire = 24.6 amperes
Current in common wire 24.6 × 1.41 = 34.7

Example 7. For load conditions as in Example 5 above:

Current in each outside wire = 234.6 amperes
Current in common wire 234.6 × 1.41 = 330

330. Combining Loads having Different Power Factors. The methods used in the previous paragraphs for finding the combined loads are strictly accurate only when the entire load has the same power factor. The power factors of various loads are given in Table 43. The error in using the approximate method is greatest when there is a large difference in power factor. Since, however, it gives values which are too high, the error is on the safe side. In applying the more accurate method, the current required for loads having the same power factor is first found. Each current thus determined is multiplied by a "reactive factor" and "resistance factor" taken from Table 44. The total resistance and reactive parts are then found by addition. The actual current is found by squaring each of these sums, adding the results and extracting the square root.

Example. Referring to Example 2 in paragraph 327:

	Resistance part	Reactive part
Flame arcs	75 × 0.60 = 45	75 × 0.80 = 60
Cooper Hewitt lamps	57 × 0.85 = 48.5	57 × 0.53 = 30.2
	93.5	90.2

Total current $\sqrt{(93.5)^2+(90.2)^2} = 129.9$ amperes.

The sum of the two currents is 132 amperes, so it will be seen that the error in using the approximate method is not great.

331. Determining Size of Branch Circuits and Fusing. The size of branch **lighting circuits** is determined in the same way as for d.c. circuits.* For **motors**, the branch circuits must be large enough to carry a load at least 25 per cent greater than the full-load current (Rule 8*b*). The wires for **squirrel-cage induction motors** must be made larger than this because of the heavy starting current. Tables 22 and 23 give the full-load current required. A squirrel-cage motor when starting under full-load torque requires about 70 per cent of normal voltage and takes

* See paragraph 315.

from 4 to 5 times full-load current from the line. This current lasts for only a few seconds, however, so that, owing to the overload capacity of enclosed fuses, the branch circuit can be fused for from 2.5 to 3 times full-load current. When no starter is used the fuses should be from 3 to 3.5 times the full-load current. Owing to the heavy starting current required for squirrel-cage motors, the Code allows the branch circuits to be protected in accordance with column B of Table 36 even when rubber insulation is used (Rule 23*e*). If this was not done, the cost of the branch wiring would be greatly increased.

Example 1. A 20-hp., 220-volt, three-phase motor has a full-load current of 54.6 amperes. The wire must be large enough to carry at least 25 per cent overload, i.e., 68.2 amperes. The starting fuses must be rated at about $2.7 \times 54.6 = 148$ amperes. If 150-ampere fuses were used, with rubber-insulated wire, the regular rules for fusing would require a No. 00 wire. Because of Rule 23*e*, however, we can use the rating for weatherproof wire, and hence a No. 1 wire can be used. Since the starting current does not last long enough to overheat the wire, this size can safely be used even where insulated with rubber, as its normal carrying capacity is 100 amperes. This would allow the motor to carry about double full-load current when running.

The wire sizes given in Tables 22 and 23 are determined in this manner. For wires with insulation other than rubber the same allowance is not made; that is, according to the Code, the wire must be chosen in accordance with column B also. However, the inspectors will often allow induction-motor wires, when exposed, to be fused somewhat higher than the values given in column B. It is apparent that the wires will be adequately protected from injury when fused in accordance with these rules, but the motor will not be properly protected against continuous overloads, which would not cause the fuses to blow, but still would be larger than the motor could safely stand for any length of time. For this reason squirrel-cage motors should always be provided with running fuses which are cut out during the starting period by means of the starting switch or compensator.* The ordinary induction motor is rated to stand a 25 per cent overload for two hours, but it can carry greater overloads for shorter periods. Therefore the running fuses should have a rating about 50 per cent greater than the full-load current of the motor. The **slip-ring induction motor** takes about

* See paragraph 183.

full-load current for full-load torque.* The size of wire is therefore determined by the allowable overload, which should be 50 per cent as before. With these motors, however, the size of wire, when rubber insulation is used, would be determined from Column A of Table 36.

Example 2. A 20 hp., 220-volt, three-phase, slip-ring motor would require 82 amperes when running at 50 per cent overload. For rubber insulation the wire should be No. 3, or for slow-burning insulation No. 5. The running fuses can be determined by the aid of Table 39.

332. Determining Size of Feeders or Mains and Fusing. For **lighting circuits** the maximum load is used to determine the wire size as in d.c. systems. For **motor circuits,** the wire size is usually determined for the maximum running load.† Rubber-covered wire used for motor feeders or mains is selected from Column A of Table 36 and not from column B, as is allowed for branch circuits.

Example 1. Single-phase circuits, rubber insulation:

Example 3, paragraph 327,	No. 1 wire is required.

Example 2. Three-phase circuits:

Example 2, paragraph 328,	No. 2 wire is required.
Example 4, paragraph 328,	No. 8 wire is required.
Example 5, paragraph 328,	300,000 cir. mil cable is required.

Example 3. Two-phase circuits:

Example 4, paragraph 329,	No. 10 wire is required.
Example 5, paragraph 329,	No. 0000 cable is required.
Example 6, paragraph 329,	No. 10 wire is required for each outside lead, No. 8 wire for common.

Calculation of Voltage Loss

333. Increasing Size of Wire to Reduce Loss. As in d.c. systems, the circuits must frequently be made larger than the minimum size calculated in the previous paragraph, to keep the voltage loss at a reasonable figure. The values of allowable loss are given in Table 40. In calculating the drop on a.c. circuits, the d.c. chart can be used (with slight modifications, to suit the different systems), provided the sizes of circuit do not exceed the following:

* See paragraph 167.

† See paragraphs 314 and 316.

Kind of Load.	Size of Circuit.	
	In Conduit.	2.5-in. Spacing.
Incandescent lamps—60 cycles...	No. 0000	No. 00
Incandescent lamps—25 cycles...	600,000 c.m.	400,000 c.m.
Induction motors—60 cycles.....	No. 1	No. 3
Induction motors—25 cycles.....	No. 0000	No. 00
Arc lamps—60 cycles...........	No. 0	No. 1
Arc lamps—25 cycles...........	300,000 c.m.	No. 0000

The method of calculation for larger circuits will be taken up in the succeeding paragraphs. As a rule, in calculating the drop on a **lighting circuit** the actual load is used, and not the " maximum load " based on allowing 600 watts per branch. The maximum load is used only in determining the smallest size of wire which can be employed, as described in paragraph 332. For **motors** the methods of calculating the drop, as just described, can also be employed. The current used is the total current under running conditions, and not as a rule the starting current. Thus, in example (4) paragraph 328, the size of wire is determined by the running load, 28.3 amperes and, therefore, a No. 8 wire is used if the insulation is rubber. The drop would be calculated for 28.3 amperes at a power factor of 0.80. In the case of example (5), paragraph 328, the size of wire chosen (300,000 cir. mils), is fixed by the starting load, 272.3 amperes. The drop should be calculated for the running conditions, which, in this case, would be:

1 – 5 hp. motor		13.4 amperes
1 – 3		8.2
1 – 2.5		7.3
2 – 1		6.4
1 – 50		122.0
1 – 3	(spare)	8.2
		Total, 165.5 amperes

Running load $165.5 \times 0.65 = 108$ amperes. If it is suspected that the drop, when motors are starting, is excessive, this can also be calculated. It is satisfactory, however, to allow a

somewhat greater drop than for running conditions. This should not exceed a total of more than 15 per cent for the entire loss between service point and motor terminals.

334. Single-phase Circuits. When the inductive effect is neglected, the calculations are exactly the same as for a d.c., two-wire system, and the voltage loss can be determined either by the formula * or the chart. If the circuit is larger than the sizes given in the previous paragraph, so that the **inductive effect** cannot be neglected, the drop should first be found as for direct current. This value of drop is then multiplied by a "drop factor" which is found from Tables 45 and 46. The additional drop due to inductance depends upon the ratio of the reactance to the resistance and also upon the power factor. The reactance depends upon the frequency and the distance between the wires. Table 45 gives these ratios for the three frequencies in common use and for wires run in conduit or spaced the usual distances apart. The reactance ratio found from Table 45 for the particular frequency and spacing is then used in connection with Table 46 to find the drop factor. Multiplying the d.c. drop by this drop factor gives the a.c. drop.

Example 1. A two-wire feeder 150 ft. long is carrying a load of incandescent lamps totaling 50 amperes at 120 volts. The wires are in conduit and the frequency is 60 cycles. The smallest wire which could be used would be No. 6 (Table 36). The drop should not exceed 2.5 per cent (Table 40) or 3.0 volts. From the chart, Fig. 232, we find this would require a No. 3 wire. By Table 45, the reactance ratio is 0.22, and for a power factor of 1.0 (Table 46), the drop factor is 1.00. Hence the a.c. drop is 3.0 volts and No. 3 wire should be used.

For loads at different power factors an average can be used if the loads are of about the same size. If one of the loads is much larger than the others, the power factor of this load should be used.

Example 2. For the flame-arcs (power factor 0.60) and the Cooper Hewitt lamps (power factor 0.85) in Example 2, paragraph 327, a power factor of 0.70 may be used. For 130 amperes, nothing smaller than a No. 00 wire can be used. The frequency is 60 cycles, the spacing 2.5 ins. and the length of the circuit 100 ft. The d.c. drop is 2.1 volts. The ratio is 0.80 and the drop factor 1.27. Hence the a.c. drop is $1.27 \times 2.1 = 2.67$ volts. As this is less then 2.5 per cent (3 volts) the wire size is satisfactory.

* See paragraph 318.

This method of calculating drop on a line carrying several loads at different power factors is not strictly accurate, but in most cases is close enough. A more accurate method would be to calculate the drop due to each part of the load separately and then to combine them with the aid of the factors given in Table 44.

Example 3. Applying this to Example 2, using a No. 000 feeder, we have:
Flame arcs, d.c. drop, 0.96 volt, a.c. drop for 0.60 power factor, 1.32 volts.
Cooper Hewitt lamps, d.c., drop, 0.73 volt; a.c. drop for 0.85 power factor, 1.0 volt.
Combining these:

Resistance Part.		Reactive Part.
Flame arcs,	$1.32 \times 0.60 = 0.792$	$1.32 \times 0.80 = 1.056$
Cooper Hewitt lamps,	$1.00 \times 0.85 = 0.85$	$1.00 \times 0.53 = .53$
	1.642	1.586

Total drop $= \sqrt{1.642^2 + 1.586^2} = 2.28$ volts.

This method always gives slightly lower values than the approximate method. The calculations for **motor circuits** are made in a similar manner.

335. Three-phase Circuits. For a **three-wire, three-phase system,** the drop in one wire is first calculated. If the currents are the same in all the wires, the total drop is 1.73 times the drop in one wire.

Example 1. Referring to Example 1, paragraph 328, the smallest size of wire which could be used is No. 8, rubber covered. With exposed wiring, 60 cycles and a length of run of 100 ft., we find the drop from the chart to be 3.75 volts for two wires. The drop on one wire is therefore 1.87 volts. The a.c. drop on one wire is also 1.87 volts because the inductive effect can be neglected.* The total drop at the lamps is $1.73 \times 1.87 = 3.24$ volts. To keep the drop within 2.5 per cent the size would have to be increased.

Example 2. For the load given in Example 2, paragraph 328, a No. 2 wire is the smallest size allowable. The drop on a three-phase feeder of this size and 14 ft. long † carrying 57 amperes is $1.73 \times 0.13 = 0.23$ volt, since the inductive effect can be neglected.

* See paragraph 333. † See Fig. 231.

For a **four-wire, three-phase system,** the total loss across each lamp load is equal to the loss in the wire supplying that load, since there is no loss in the neutral as long as the load is balanced.

> **Example 3.** With sixty 100-watt lamps divided among the three phases, the current is 16.7 amperes in each line wire. If a No. 12 wire is used to carry this current a distance of 100 ft. the d.c. drop is 5.47 volts for two wires. The actual drop at the lamps is therefore 2.73 volts.

When the load is unbalanced, there would be some additional loss due to the drop in the neutral, but in general this is so small that it can be neglected. Since **motors** are connected only to the line wires, the method of calculation is the same for either system. The drop in one wire is figured as just described and this is multiplied by 1.73 to give the total drop across each phase.

> **Example 4.** Referring to Example 4, paragraph 328, the smallest wire size was found to be No. 8 (paragraph 332). The feeder is 300 ft. long and in conduit. Frequency, 60 cycles. By referring to the tabulation in paragraph 333, it will be seen that the inductive effect can be neglected. Using the chart, the drop for a two-wire circuit 300 ft. long is found to be 11 volts. Hence for one wire it is 5.5 volts and between phases it is $5.65 \times 1.73 = 9.5$ volts. The allowable drop is 6 per cent or 13.2 volts (Table 40). Hence No. 8 wire is satisfactory.

> **Example 5.** Referring to Example 5, paragraph 328, the wire size is 300,000 cir.mils (paragraph 332). The feeder is 300 ft. long and in conduit. The power factor, determined from the 50 hp. motor, would be 0.85 (Table 43). The maximum running current is 108 amperes (paragraph 333). By the chart, the drop on a two-wire circuit is found to be 2.3 volts. Hence the three-phase drop is $1.15 \times 1.73 = 1.98$ volts. The frequency is 60 cycles and hence the inductive effect cannot be neglected (paragraph 333). The ratio of reactance to resistance is 1.01 (Table 45). The drop factor for a power factor of 0.85 is 1.39 (Table 46). Hence the drop is $1.98 \times 1.39 = 2.75$ volts, which is less than the maximum allowable drop. The size need not, therefore, be increased.

When the wires are run exposed, they are usually installed side by side and hence the spacing between wires varies. Thus if a spacing of 2.5 in. between adjacent wires were used, the distance between the outside wires would be 5.0 in. As a result, the drop on the two outside wires would be somewhat greater than the drop on the middle wire. The average drop on the wires can be approximately determined by calculating for a

spacing 50 per cent greater than the distance between the centre and either outside wire. Thus, for wires 6 in. apart, calculate the drop on a wire assuming the return 9 in. away. This drop multiplied by 1.73 will give the approximate drop between phases. If the wires are transposed, that is, if each wire is in the centre for one-third the distance, use a spacing 26 per cent greater than the spacing between adjacent wires.*

336. Two-phase Systems. In a **four-wire two-phase system,** each phase can be calculated independently like single-phase circuits.† For a **three-wire, two-phase system** the drop in the common wire causes an unbalancing effect upon the voltages, but for interior wiring this is not serious. The calculation of drop for this system is too complicated to be given here. An approximate result can be obtained by calculating the drop on the outside wire in the regular way. To this can be added 0.707 times the drop in the common wire.

* H. B. Dwight, Electric Journal, July, 1915.

† See paragraph 334.

CHAPTER 21

EXAMPLES OF WIRING SYSTEMS

Wiring System for an Office Building

337. There are seventeen floors above the street level and two below. The first four floors and the basement are used for exhibition, sales rooms and executive offices, while the remainder of the floors are used for ordinary offices. Fig. 236 shows the arrangement of a typical office floor.

338. Power Supply. Both lighting and power service is supplied by a steam-driven plant in the sub-basement. The service is 240–120 volts, three-wire, direct current. Three-wire Edison service is also provided through supply feeders 1 and 2. All the wiring is in rigid conduit concealed in walls and floors. Lamps are supplied at 110 volts and motors at 220 volts. The switchboard consists of three generator panels, two motor panels and three lighting panels.

339. Feeder System. There are 22 lighting feeders and 11 power feeders. The lighting feeders are three-wire with neutral the same size as the outers and the power feeders are two-wire (Figs. 237–8). These feeders are divided between two rising points near either end of the building. Feeders *A* and *B* supply lighting service to the offices and feeders *C* supply stair, corridor and toilet lighting. The elevators are supplied on feeders separate from those for the ventilating fans, etc. The small ventilating fan motors are supplied at 110 volts from panels *A* and *B* on the second and third floors. Each lighting feeder supplies three panel boards, one above and one below the floor where the feeder terminates. Three-pole switches are provided in the middle panel, through which the mains to the other two panels are supplied. In some cases, feeders *C* supply five floors instead of three.

340. Panel Boards. The lighting panel boards (Fig. 237), have two-wire, 110-volt branches with 10-ampere knife switches

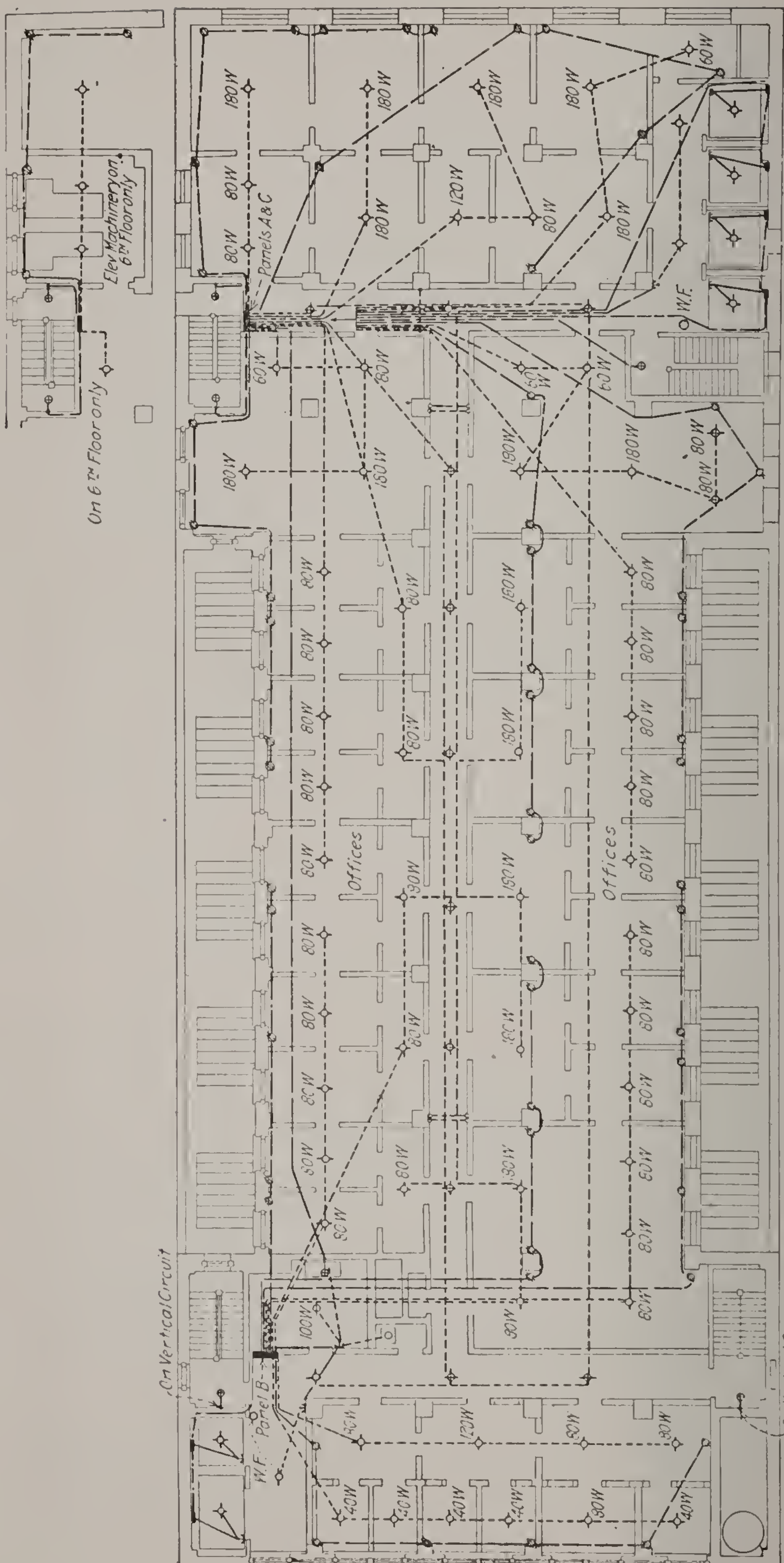
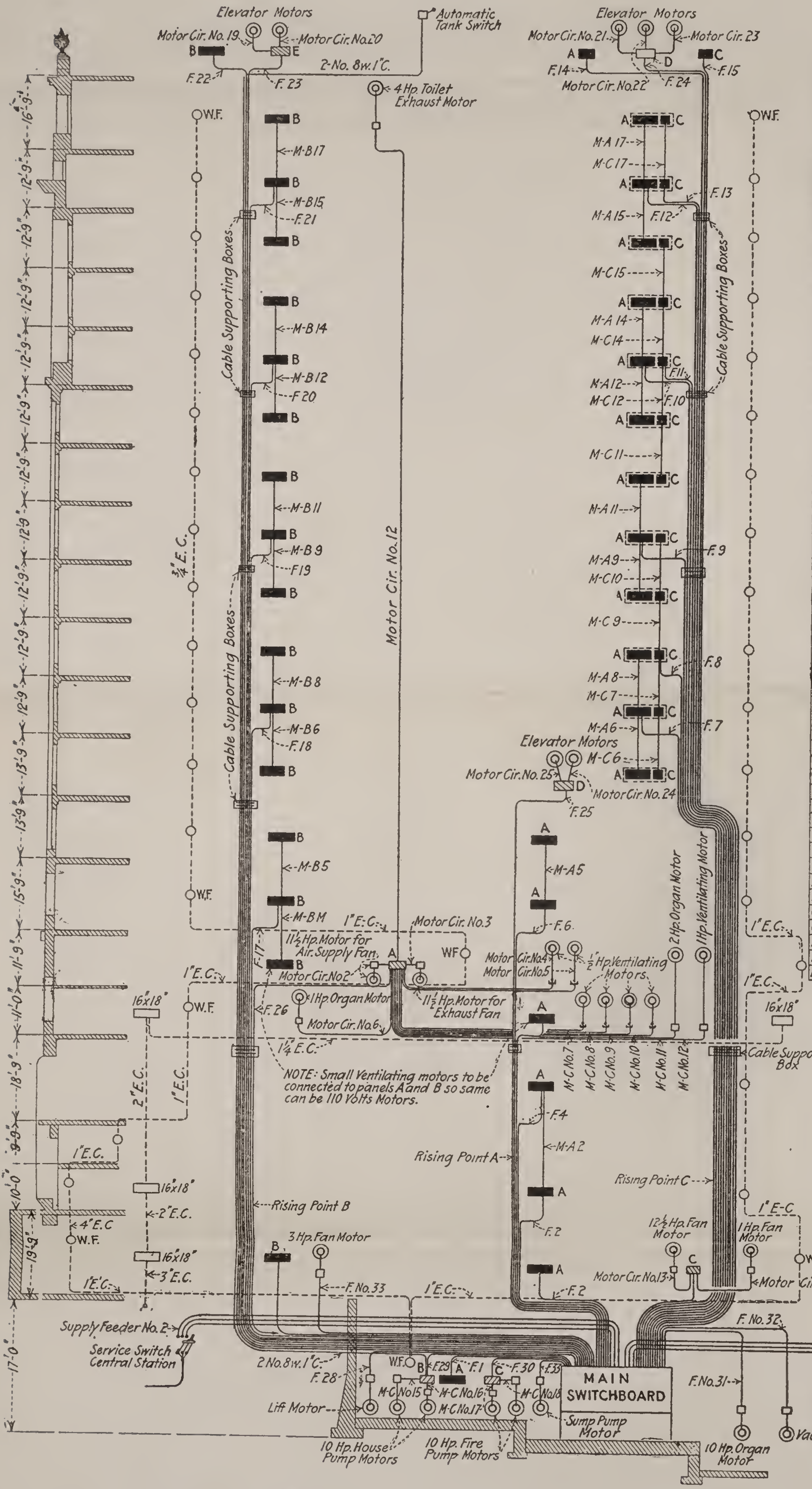


FIG. 236.—Wiring for an Office Building. Floor Plan.
(Mr. C. E. Knox, Consulting Engineer.)



CUT-OUTS

NAME	FLOOR	HAS CONNECTION FOR: MAINS	BRANCH CIRCUIT	P.B. SWITCHED	TASTING PLUG & RECEPTACLES	KNIFE SWITCHES: 25 AMPERES	T.P.S.T. 50 "	T.P.S.T. 100 "	T.P.S.T. 150 "	T.P.S.T. 200 "	T.P.S.T. 300 "	D.P.S.T. 25 "	D.P.S.T. 50 "	D.P.S.T. 100 "	D.P.S.T. 150 "	D.P.S.T. 200 "	D.P.S.T. 300 "	METER LOPS
A	S.B	-	14	6	1													
A	B	-	24	4	1													
A	G^R	1	48	36	1		3	1										
A	2nd	-	72	62	1		3											
A	3rd	-	36	8	1													
A	4th	1	22	14	1		1											
A	5th	-	20	14	1													
A	6th	-	16	-	1													
A	7th	2	16		1		2											
A	8th	-	18		1													
A	9th	-	16		1													
A	10th	2	16		1		2											
A	11th	-	16		1													
A	12th	-	16		1													
A	13th	2	16		1		2											
A	14th	-	16		1													
A	15th	-	16		1													
A	16th	2	16		1		2											
A	17th	-	18		1													
A	R	-	20		1		1											
B	B	-	34	22	1													
B	M	-	20	2	1													
B	4th	2	16	8	1		2											
B	5th	-	16	8	1													
B	6th	-	14		1													
B	7th	2	14		1		2											
B	8th	-	16		1													
B	9th	-	14		1													
B	10th	2	14		1		2											
B	11th	-	14		1													
B	12th	-	14		1													
B	13th	2	14		1		2											
B	14th	-	14		1													
B	15th	-	14		1													
B	16th	2	14		1		2											
B	17th	-	14		1													
B	R	-	20		1		1											
C	6th	-	10	8														
C	7th	1	6	4		1												
C	8th	2	6	4		2												
C	9th	1	6	4		1												
C	10th	-	6	4														
C	11th	-	6	4														
C	12th	1	10	8		1												
C	13th	2	6	4		2												
C	14th	1	6	4		1												
C	15th	-	6	4														
C	16th	1	6	4		1												
C	17th	-	6	4														
C	R	-	20	-	1	1	1											
A	M		10									2	2					
B	SB												2					
C	SB												2					
C	B											2	1					
D	6th														2			
D	R														3			
E	R														2			

FIG. 237.—Wiring for an Office Building. Riser diagram. *To face page 339.*
(Mr. C. E. Knox, Consulting Engineer.)

OUTLETS AND SYMBOLS

LOCATIONS / OUTLETS	CEILING CHANDE.	REFLECTOR UNIT	RECEPTACLE LIGHT	DROP CORD	WALL BRACKET	GOOSENECK BR'T	INSERTION PLUG	FLOOR PLUG	STEREOPTICON PLG	WALL EXTENSION	AUTO. DOOR SW.	P.B. SWITCH	EXIT LIGHT	JUNCTION BOX	POWER PLUG	CEILING EXTENSION	CALL BELL	TEL. WALL TYPE	TEL. DESK TYPE	SERVICE BOX	FLOOR OUTLET FOR TEL.	WATCHMAN & FIRE ALARM STATION (WF)
Roof		3			4					2		3							S			
17th Floor	30	14		3	6		59					3										2
16th "	31	14		1	6		58					3										2
15th "	31	15		1	6		58					4										2
14th "	31	14		1	6		58					3										2
13th "	31	14		1	6		58					3										2
12th "	31	15		1	6		58					4										2
11th "	31	14		1	6		58					3										2
10th "	31	14		1	6		58					3										2
9th "	31	15		1	6		58					4										2
8th "	36	14		1	6		58					8		5								2
7th "	31	14		1	6		58					3										2
6th "	30	14		1	6		58					3										2
5th "	44	7		1	12		13					11			2	3		2				2
4th "	44	7		1	12		13					11			2	3		2				2
3rd Fl Mezza	1	25	9		8							17			8			1				2
3rd Floor	21	38	2	5	14		13	1				33		2	18			1	5			1
2nd "	27	6	5		15	1	2		1	2	1	11	4		4	1			2			1
Ground Fl. Mezza																						1
" Floor	13	4	62	4	2		1			12		10	6	3	4	5	2	2				2
Basement	27	57	92	2	22	2	10			1		62			17		1	4		16	2	2
Sub-Bas. Mezza																						
Sub-Basement		28	15	9			7					14						1				1
Total	552	346	185	36	151	3	756	1	1	17	1	216	10	10	55	12	3	13	7	16	2	38

LIGHTING FEEDERS

NUMBER	TERMINATES AT: FLOOR	TERMINATES AT: CUT-OUT	BRANCH CIR'S	ESTIMATED LOAD IN AMP.	LENGTH IN FT. (ONE WAY)	LOSS IN VOLTS ON EACH SIDE	SIZE OF WIRE: MIDDLE CONDUCTOR	SIZE OF WIRE: OUTSIDE CONDUCTOR	MINIMUM INSIDE DIAM. OF CONDUIT ALLOWED
1	S-B	A	14	35	80	2.3	No. 6	No 6	1"
2	B	A	24	60	140	3.5	3	3	1½"
3	G	A	48	120	155	2.4	000	000	2½"
4	2nd	A	72	180	180	2.8	250 000	250 000	2½"
5	3rd	A	36	90	190	2.3	00	00	2½"
6	4th	A	42	105	210	2.8	000	000	2½"
7	7th	A	50	125	260	3.5	00	00	2½"
8	8th	C	34	85	280	2.5	00	00	2½"
9	10th	A	48	120	305	3.2	000	000	2½"
10	13th	A	48	120	350	3.5	000	000	2½"
11	13th	C	34	85	350	2.5	000	000	2½"
12	16th	A	50	125	395	3.4	0000	0000	2½"
13	16th	C	12	30	395	2.5	2	2	2"
14	R	A	20	50	440	3.6	00	00	2½"
15	R	C	20	50	500	4	00	00	2½"
16	B	B	34	85	120	3.3	2	2	2"
17	4th	B	42	105	200	3.4	00	00	2½"
18	7th	B	44	110	250	3.	00	00	2½"
19	10th	B	42	105	295	3.3	00	00	2½"
20	13th	B	42	105	340	3.1	000	000	2½"
21	16th	B	42	105	390	3.5	000	000	2½"
22	R	B	20	50	415	3.3	00	00	2½"

FIG. 238.—Wiring for an Office Building. Data on outlets and lighting feeders.

(Mr. C. E. Knox, Consulting Engineer.)

and enclosed fuses. Panels on the same floor, supplied from feeders *A* and *C* are both located in the same cabinet. Each

MOTOR CIRCUITS

NUMBER	SERVICES FOR SUPPLYING CURRENT TO	HP. SUPPLIED	LENGTH IN FT. (ONE WAY)	CURRENT IN AMP.	SIZE OF WIRE	MINIMUM INSIDE DIAM. OF CONDUIT ALLOWED
1	Toilet Exh. Fan	4	250	16	No. 8	1"
2	Air Supply Fan	11½	35	46	No. 4	1¼"
3	Exhaust Fan	11½	40	46	No. 4	1¼"
4	Vent. Motor	½	100	2	No. 14	½"
5	" "	½	90	2	No. 14	½"
6	Organ Motor	1	70	4	No. 14	½"
7	Vent. Motor	½	125	2	No. 14	½"
8	" "	½	125	2	No. 14	½"
9	" "	½	110	2	No. 14	½"
10	" "	½	110	2	No. 14	½"
11	Organ Motor	2	180	8	No. 10	¾"
12	Vent. Motor	1	180	4	No 14	½"
13	Fan Motor	12½	25	50	No. 3	1¼"
14	" "	1	110	4	No. 14	½"
15	Housepump M.	10	30	40	No. 4	1¼"
16	" "	10	35	40	No. 4	1¼"
17	Fire Pump Motor	10	30	40	No. 4	1¼"
18	" " "	10	35	40	No. 4	1¼"
19	Elevator Motor	40	25	160	No 4/0	2"
20	" "	35	25	140	No. 4/0	2"
21	" "	35	25	140	No 4/0	2"
22	" "	35	25	140	No 4/0	2"
23	" "	35	25	140	No. 4/0	2"
24	" "	35	25	140	No 4/0	2"
25	" "	35	25	140	No. 4/0	2"

LIGHTING MAINS

NUMBER	SUPPLIED BY: FEEDER	CUT-OUT	FLOOR	BRANCH CIR'S	ESTIMATED LOAD IN AMP.	LENGTH IN FT. (ONE WAY)	LOSS IN VOLTS ON EACH SIDE	SIZE OF WIRE: MIDDLE CONDUCTOR	OUTSIDE CONDUCTOR	MINIMUM INSIDE DIAMETER OF CONDUIT ALLOWED
A 5	6	A	4th	20	50	17		No 4	No 4	1½"
A 6	7	A	7th	16	40	15		No. 6	No. 6	1¼"
A 8	7	A	7th	18	45	15		No 6	No. 6	1¼"
A 9	9	A	10th	16	40	15		No 6	No 6	1¼"
A 11	9	A	10th	16	40	15		No. 6	No 6	1¼"
A 12	10	A	13th	16	40	15		No 6	No 6	1¼"
A 14	10	A	13th	16	40	15		No 6	No 6	1¼"
A 15	12	A	16th	16	40	15		No 6	No 6	1¼"
A 17	12	A	16th	18	45	15		No 6	No 6	1¼"
BM	17	B	4th	20	50	15		No. 5	No 5	1¼"
B 5	17	B	4th	16	40	16		No 6	No 6	1¼"
B 6	18	B	7th	14	35	15		No. 6	No 6	1¼"
B 8	18	B	7th	16	40	15		No. 6	No 6	1¼"
B 9	19	B	10th	14	35	15		No 6	No 6	1¼"
B 11	19	B	10th	14	35	15		No. 6	No 6	1¼"
B 12	20	B	13th	14	35	15		No. 6	No 6	1¼"
B 14	20	B	13th	14	35	15		No 6	No 6	1¼"
B 15	21	B	16th	14	35	15		No 6	No 6	1¼"
B 17	21	B	16th	14	35	15		No 6	No 6	1¼"
C 6	8	C	8th	10	25	15		No 8	No 8	1"
C 7	8	C	8th	16	40	15		No 6	No. 6	1¼"
C 9	8	C	8th	12	30	15		No 8	No 8	1"
C 10	8	C	8th	6	15	15		No. 10	No 10	1"
C 11	11	C	13th	6	15	15		No. 10	No 10	1"
C 12	11	C	13th	16	40	15		No 6	No 6	1¼"
C 14	11	C	13th	12	30	15		No 8	No 8	1"
C 15	11	C	13th	6	15	15		No 10	No 10	1"
C 17	13	C	16th	6	15	15		No 10	No 10	1"
A 2	3	A	6r Fl.	40	100	28		No 0	No 0	2"

SUPPLY FEEDER

NUMBER	ESTIMATED LOAD IN AMP. AT 240 VOLTS	NUMBER OF CONDUCTORS	SIZE OF EACH CONDUCTOR	NUMBER OF CONDUITS	MINIMUM INSIDE DIAMETER OF CONDUIT ALLOWED	ESTIMATED LENGTH IN FT. (ONE WAY)
1	2000	6	No 2,000,000	6	3½"	200'
2	2000	6	No 2,000,000	6	3½"	140'

POWER FEEDERS

NUMBER	TERMINATES AT	HP SUPPLIED	ESTIMATED LOAD IN AMP.	LENGTH IN FT. (ONE WAY)	LOSS IN VOLTS ON EACH SIDE	SIZE OF WIRE	MINIMUM INSIDE DIAMETER OF CONDUIT ALLOWED
23	E. Roof	75	300	415		No 500,000	3"
24	D Roof	105	420	440		600 000	3"
25	D 6th Floor	70	280	260		400 000	3"
26	A Mezza	34	136	240		00	2"
27	C Basement	13½	54	135		2	1½"
28	Lift Motor	12½	50	125		2	1½"
29	House Pump	20	80	45		2	1½"
30	Fire Pump	20	80	96		2	1½"
31	Organ Motor	10	40	100		4	1¼"
32	Vacuum Clean.			55		4	1¼"
33	Sump Pump			90		8	1"

FIG. 239.—Wiring for an Office Building. Data on feeders and mains.
(Mr. C. E. Knox, Consulting Engineer.)

cabinet has a compartment for push-button switches, which control the corridor lights supplied by feeders *C*. The cabinets are steel, with steel door and trim finished to match the decora-

tions of the corridor. On the office floors there are about 16 branch lighting circuits for each of the two panel boards supplying the floor. The power panel boards (Fig. 239), have from two to four double-pole, fused switches for supplying the individual motors.

341. Arrangement of Branch Circuits. The lighting circuits each supply from three to six outlets (Fig. 236). Plug receptacles located in the wall about 18 in. above the floor are provided in most of the rooms. These are supplied by separate branch circuits. The lamps in the ordinary offices are controlled by pendant switches attached to the lighting fixture.

342. Lighting System. The ordinary offices are lighted by the direct system, using fixtures with two or three arms and translucent glass reflectors ("Opalux"). Each arm carries a 40- or 60-watt tungsten lamp. The lighting of the lower floors, which are used for sales, exhibition and executive offices, is by the semi-indirect system.

343. Auxiliary Circuits. An idea of the various kinds of service provided can be obtained from Fig. 238, which gives the list of outlets. Two combined fire-alarm and watchman's stations are located on each floor in the corridors.

Installation in a Collar Factory

The arrangement of circuits on one floor of a nine-story building is shown in Fig. 240.

344. Lighting. Energy for lighting is supplied at 125 volts from a four-wire, three-phase system. The lamps are connected between the outside wires and the neutral. Each lighting feeder is made up of three wires, one being connected to the neutral and the other two across one of the phases. The feeders are distributed on the three phases to balance the load. The spacing of the units is rather wide—about 22 by 18 ft.—because the floor shown is used for storage and rough manufacturing. Exit lamps and emergency lamps on circuits separate from the regular supply are provided. The lamps are supplied from five panel boards on each floor and are controlled by switches on these panels. All wiring is in conduit.

345. Power. The motors are connected across the three phases and hence operate at about 217 volts. Separate feeders and panel boards are provided for the power supply.

Lighting Installation for a Machine Shop

346. In Fig. 241 is shown a portion of a floor in a light machine shop, with a low ceiling (about 13 ft.). The work is on small

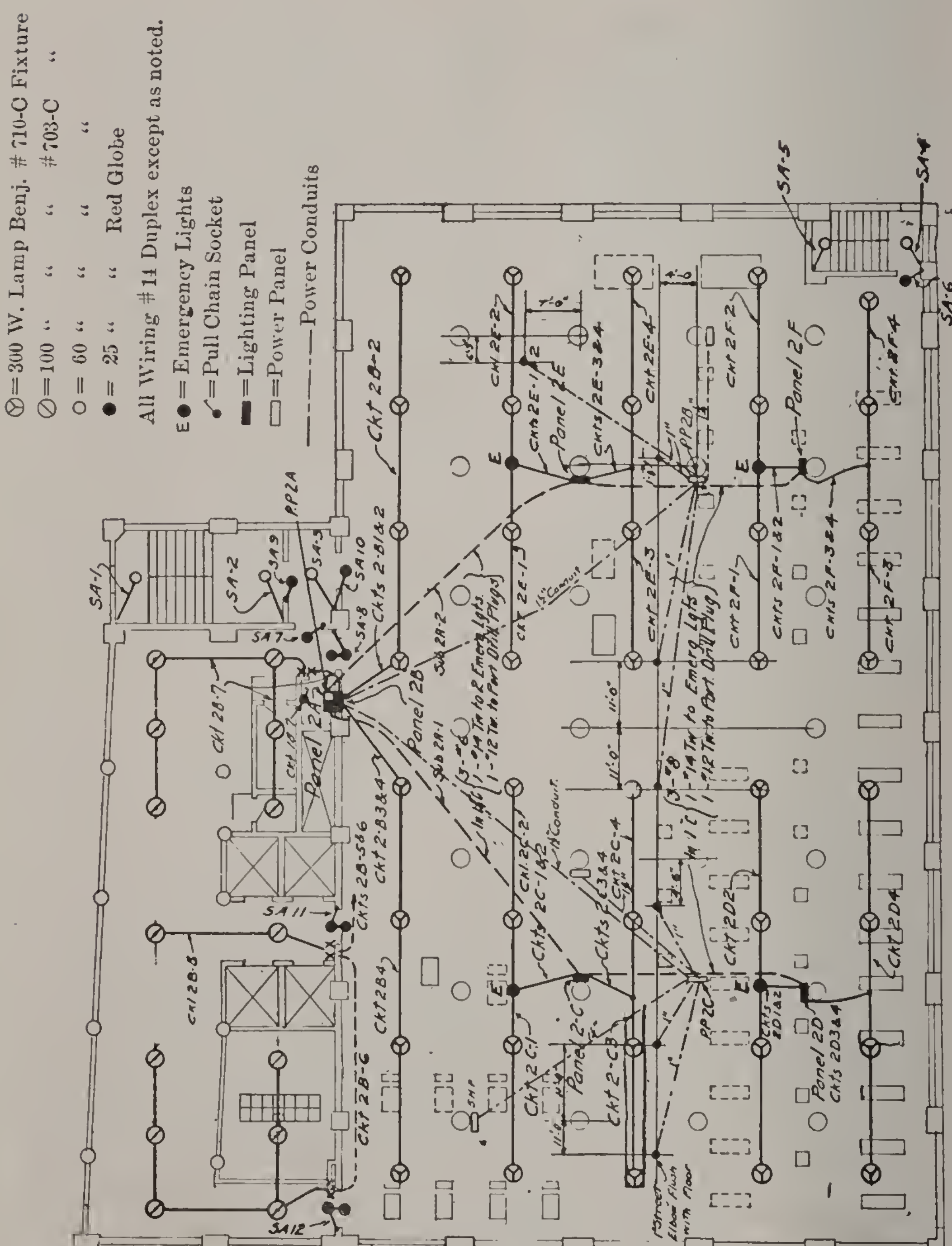


Fig. 240.—Lighting and Power Installation for a Factory. Arrangement with wide spacing of lighting units. (Westinghouse, Church, Kerr & Co.)

parts and, therefore, a close spacing of the units—about 9×9 ft.—is required. Emergency lighting and exit lamps are provided. The units are equipped with deep bowl, enamel-steel reflectors, supported from No. 14 reinforced cord. Because of this

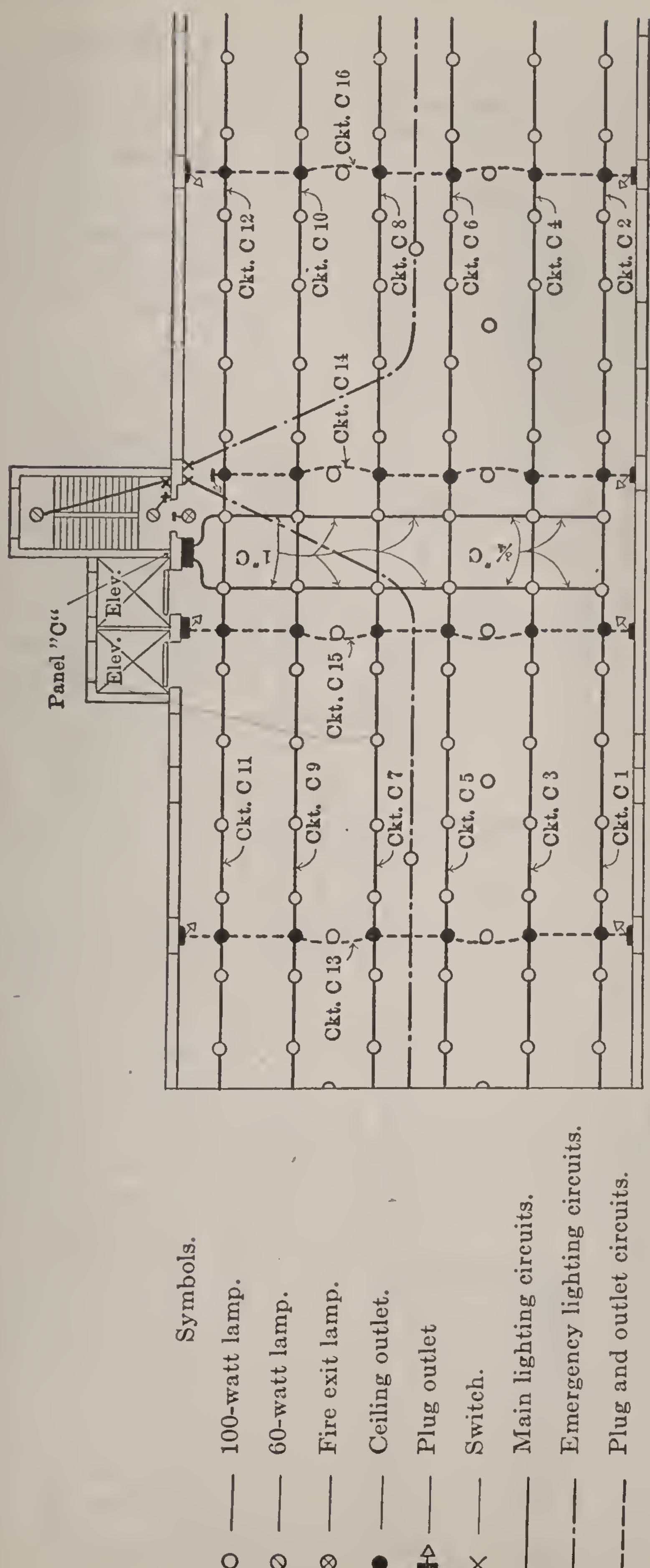


FIG. 241.—Lighting Installation for a Factory.

Arrangement with close spacing of units. Illustration shows only the portion of the floor supplied by panel "C." (Westinghouse, Church, Kerr & Co.)

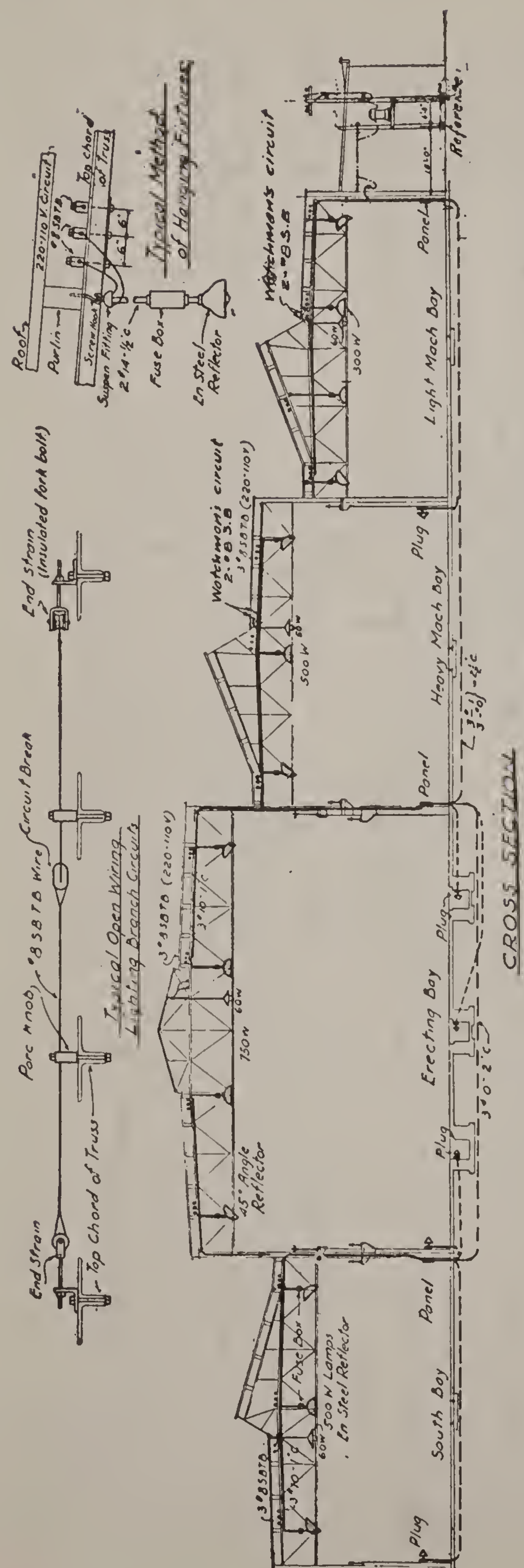


FIG. 242.—Sectional View of Large Machine Shop.
Showing method of installing lighting units. (Westinghouse, Church, Kerr & Co.)

arrangement, 1320 watts can be allowed on one circuit. Plug outlets are provided, on circuits separate from the lamps, but using the same conduits.

Lighting Installation for a Railroad Repair Shop

347. An arrangement for a shop with relatively high ceilings is shown in Fig. 242. The lamps are supplied on a 220–110 volt, three-wire, a.c. system. This is furnished by transformers stepping down from 440 volts, which is the voltage used for the motors. The mains which have slow-burning insulation are run open on insulators located on the roof trusses (Fig. 242). Taps are taken from these mains for the lighting units, each of which is fused, as shown in the illustration. A special feature is the use of angle steel re-

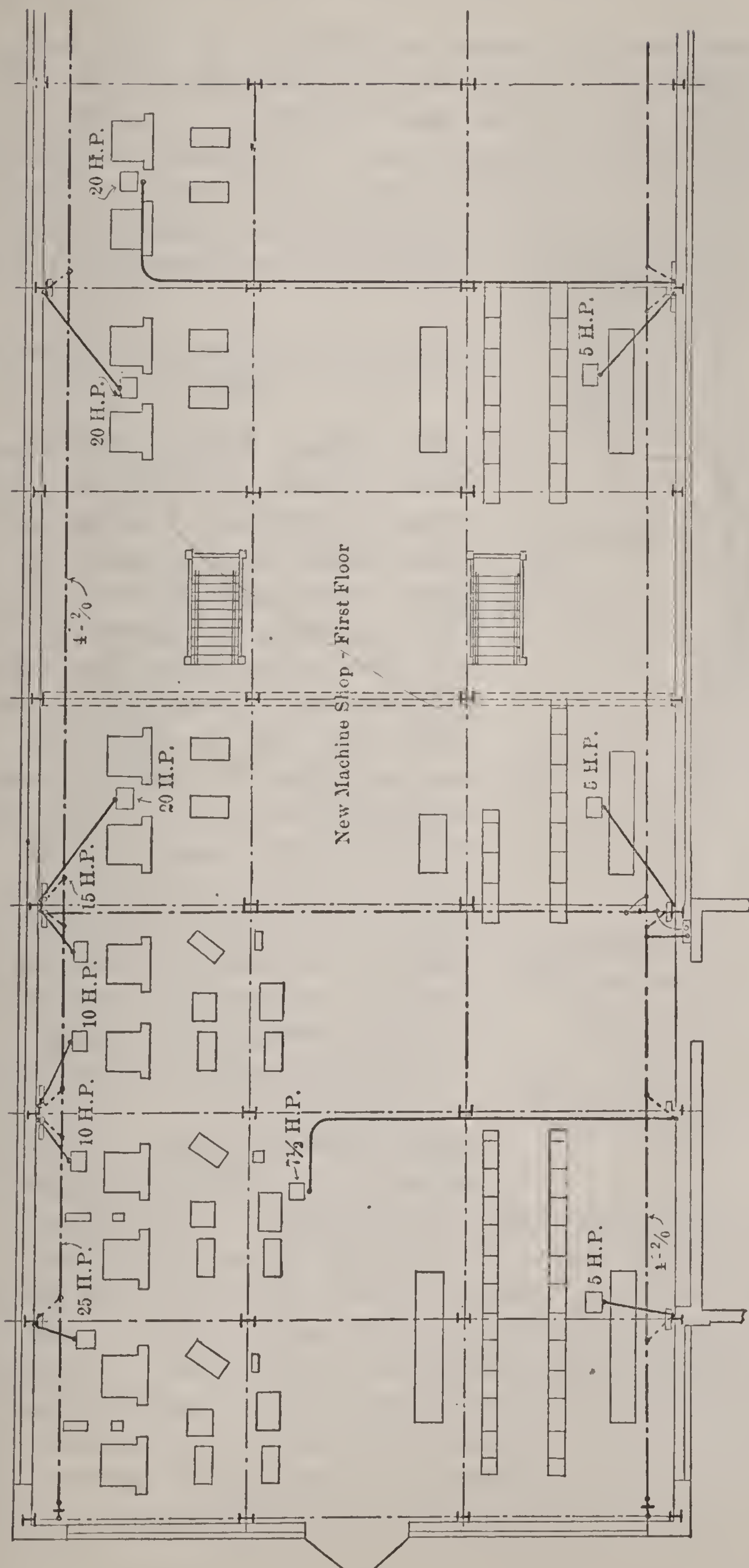


FIG. 243.—Motor Layout for Group Drive.
(Westinghouse, Church, Kerr & Co.)

flectors near the walls better to distribute the light and give proper lighting on the benches near the walls. Plug outlets are provided, but the overhead lighting is intended to be sufficient for the usual requirements. The mains are separated about every 75 ft. by section breaks, and these sections are controlled from panels located on the columns at convenient intervals.

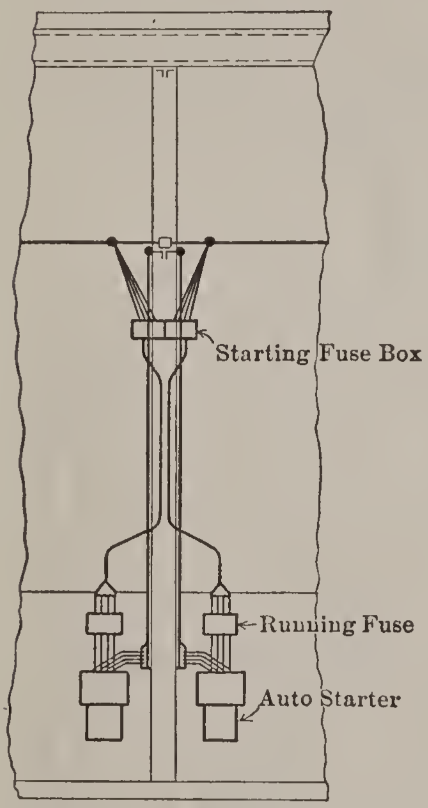


FIG. 244.— Arrangement of Motor Branch Circuits. Group Drive.

This shows method of mounting auto-starter and fuses for the motors shown in Fig. 243. (Westinghouse, Church, Kerr & Co.)

POWER INSTALLATION FOR MACHINE SHOPS

348. Group Drive. The installation shown in Fig. 243 illustrates one method of wiring motors where group drive is used. A two-phase, 220-volt system is employed. The mains are run open on cleats and are located near the ceiling. Slow-burning insulation is used. Mains are run the length of the shop, at either side and the branch circuits are tapped off at convenient intervals. No panel boards are used, since the motors are too scattered to make this arrangement feasible. In Fig. 244 is shown the method of installing the auto-starters and the starting and running fuses. The branch circuits to the motors are in conduit.

349. Individual Drive. The plan shown in Fig. 245 is typical of a machine shop doing fairly heavy work. This is part of a locomotive repair shop. Most of the motors are operated on a 440-volt, three-phase, 60-cycle system, but a few are supplied with 230 volts, direct current. The latter system is used only for variable-speed tools and a few of the cranes. Most of the cranes, including one of 150-ton capacity, are operated from the a.c. supply. The d.c. cranes were taken from another shop. All the new crane installation is alternating current. The amount of the d.c. load is kept as small as possible to reduce the

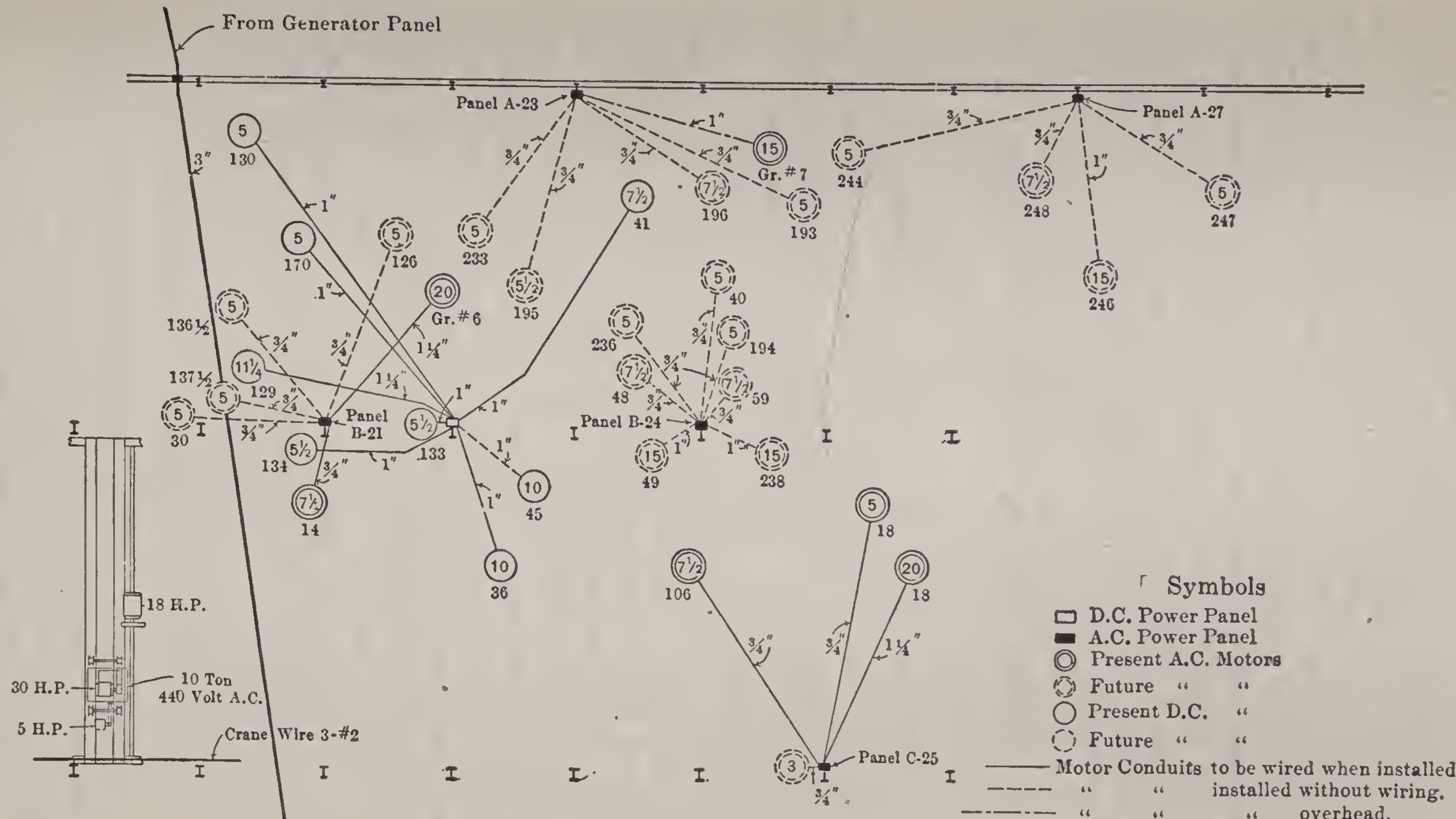


FIG. 245.—Motor Layout for Individual Drive.

The figure in the circle is the horsepower of the motor. The figure at the side is the number of the motor. Note the provision for additional motors. (Westinghouse, Church, Kerr & Co.)

size of the motor-generator set required for this purpose. It will be noted that, in addition to the individual-drive motors, there are two operating group drives (Groups 6 and 7). The mains, which are not shown, are run open, near the ceiling along each of the columns. These mains consist of wire with slow-burning insulation, supported on porcelain cleats and held tight by strain insulators at each end. Taps from the mains supply panel boards located on the columns. These taps are in conduit. The panel boards contain a fused main switch and fuses for each branch circuit. The branch wiring is all in conduit. Motors up to 5 hp. capacity are started by a two-throw switch which cuts out the running fuses when it is in the starting position. Large motors have auto-starters and running fuses or overload relays.

Lighting Installation for a Hotel

350. Fig. 246 shows a portion of one floor of a high-class hotel and illustrates the arrangement for the guests' rooms. The lighting is supplied by a 240–120 volt, three-wire, d.c. system. All wiring is in rigid iron conduit concealed in the floors and walls. Panel boards on each floor supply the branch circuits. The panel boards contain a three-pole, fused main switch. Each branch circuit is provided with fuses and a knife switch. The lighting feeders are so designed that the drop between service switchboard and the furthest panel board is not more than 3.5 volts on either side of the neutral with all the lights burning. The corridor lamps are placed on two circuits, which are staggered, so that half of the lamps can be extinguished late at night. Each bedroom is provided with a wall receptacle which can be used for a table light, etc. Wall brackets are located on each side of the dresser. General illumination of the room is provided by a ceiling outlet with a semi-indirect fixture.

Lighting Installation for a Residence

351. The plans shown in Figs. 247 and 248 illustrate a lighting installation for a moderate-sized residence. The service enters underground with the meter, service switch and cutout in the basement. From this point, the circuit runs to the panel board on the first floor. All wiring is in rigid conduit. In all of the

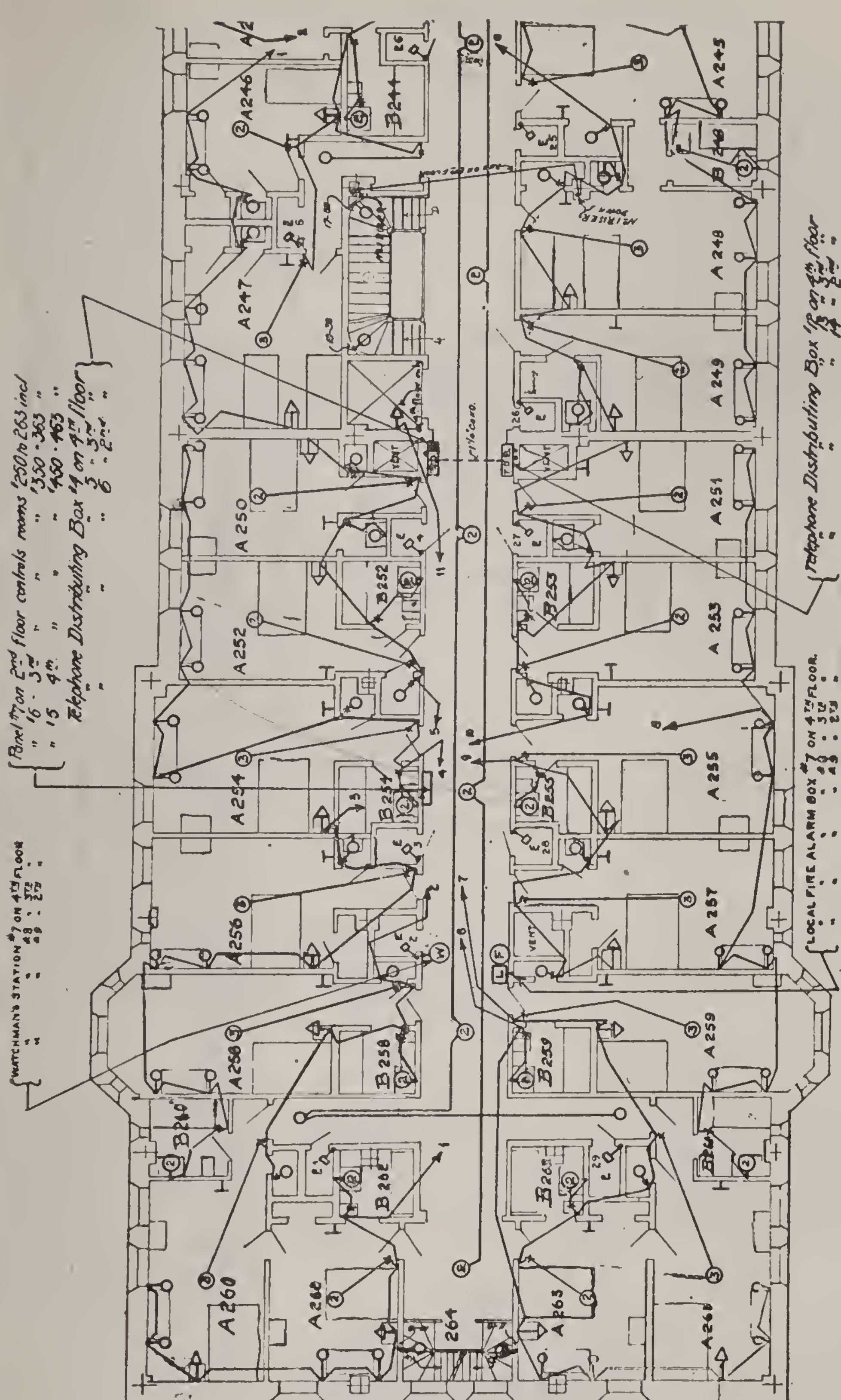


FIG. 246.—Lighting Installation for a Hotel. Guests' rooms. (Westinghouse, Church, Kerr & Co.)

Symbols

- Ceiling Outlet 1 light
- Wall " 1 "
- Ceiling " more than 1 light
- Wall " " " " "
- " Base Plug
- Floor Plug
- D.P. Push Switch 4′0″ above floor

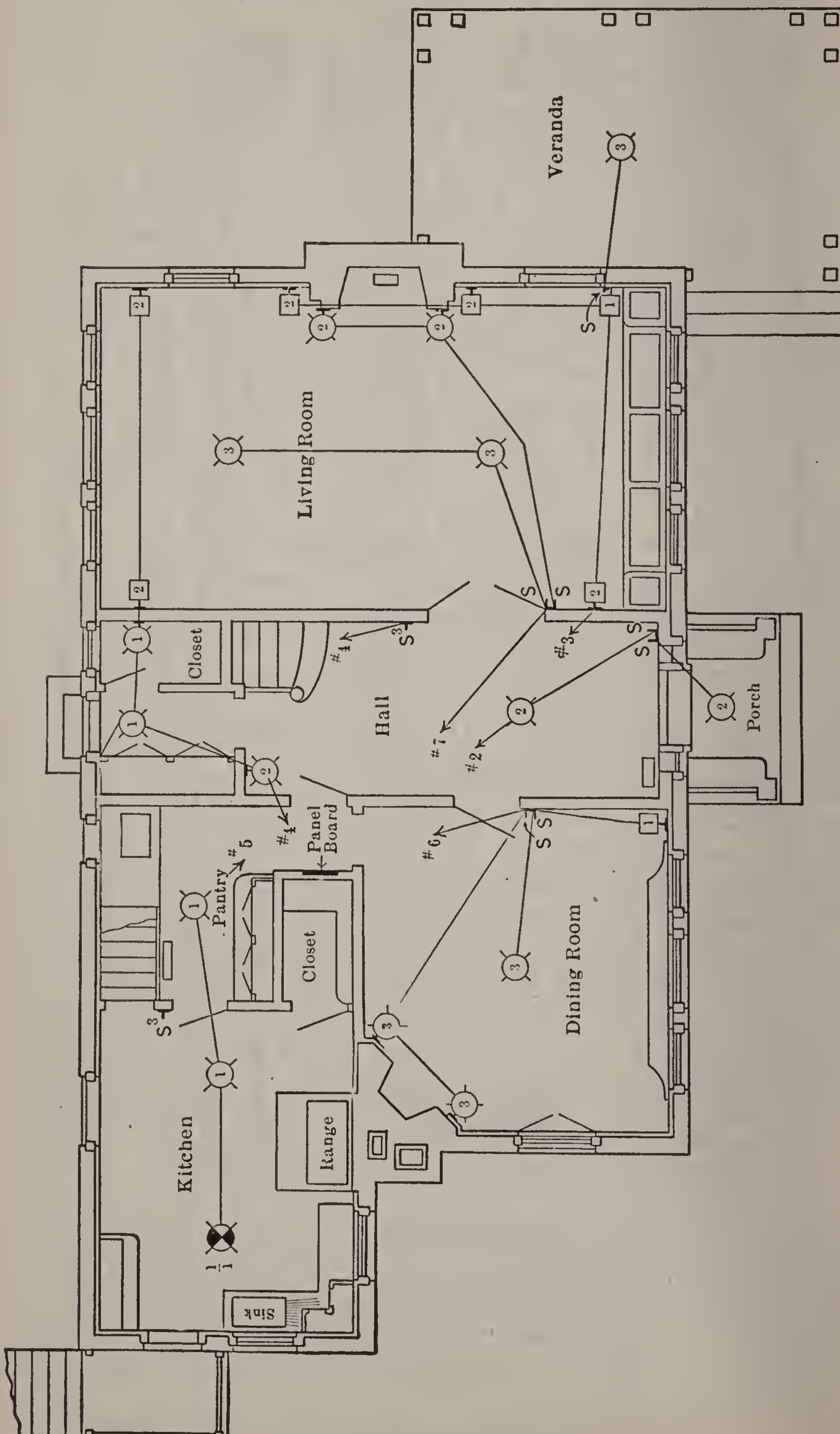


FIG. 247.—Lighting Installation for a Residence. First-floor plan.

large rooms on the first floor, the lamps are controlled by push-button switches. Plug outlets are provided in the living-room for reading lamps, vacuum cleaner, luminous heaters, etc. The plug outlet in the dining-room is for various cooking devices. The lamp in the upper hall is controlled by three-way switches

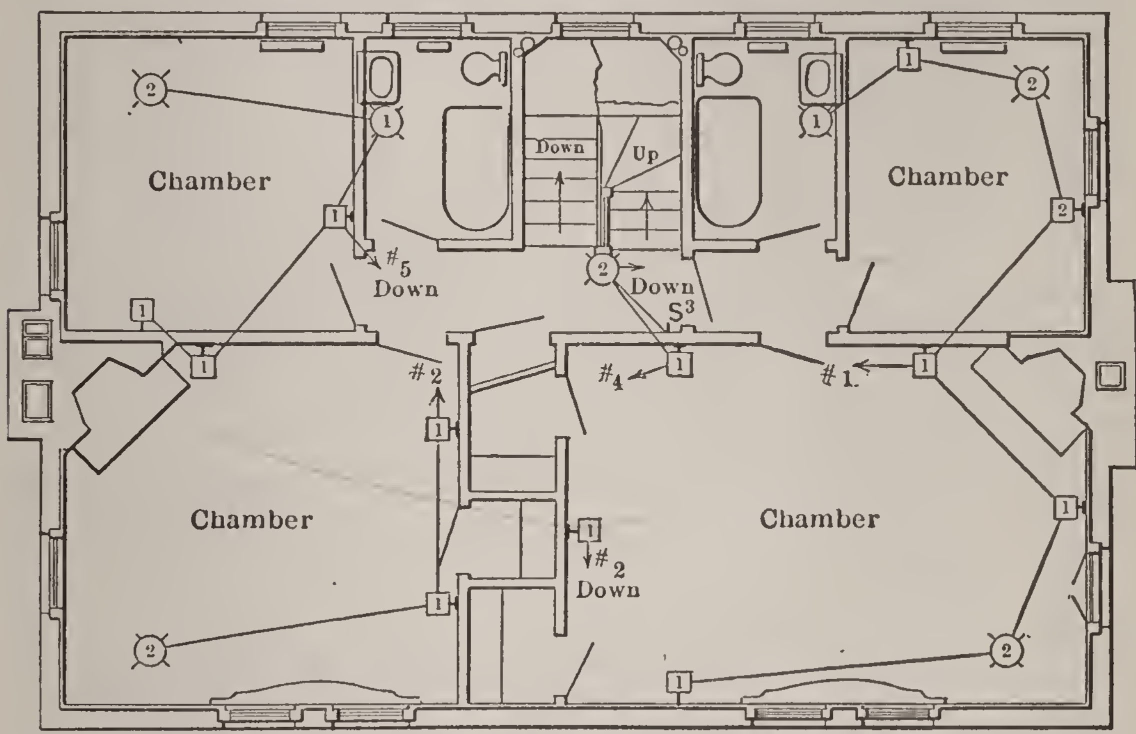


FIG. 248.—Lighting Installation for a Residence. Second-floor plan.

located on the first and second floors so that the lamp can be lighted or extinguished at either place. Each chamber is provided with a ceiling outlet over the dresser. Plug outlets are supplied to accommodate a table lamp, luminous heater, and similar devices.

APPENDIX A

The paragraph number after each heading refers to the place in the text where a further description of the table may be found.

TABLE 1. (Par. 22)

DATA ON METALLIZED-FILAMENT (GEM) LAMPS

Rated Watts.	Candle-power.*	Rating, Watts per Candle.*	Total Output, Lumens.	Lumens per Watt.	Rated Life.†	Amperes at 120 Volts.	Amperes at 240 Volts.
20	5.0	4.0	52.0	2.60	1000	0.167	0.083
30	10.0	3.0	103.8	3.46	1000	0.250	0.125
40	15.6	2.56	162.0	4.05	600	0.333	0.167
50	20.0	2.50	207.5	4.15	700	0.416	0.208
60	24.0	2.50	249.0	4.15	700	0.500	0.250

* Mean horizontal candlepower.

† See paragraph 8.

Lamps of the above sizes may be obtained for voltages from 105 to 125.

TABLE 2. (Par. 28)

DATA ON MAZDA B (VACUUM-TYPE) LAMPS FOR CONSTANT POTENTIAL CIRCUITS *

	Rated Watts.	Mean Spherical C.P.	Rating Watts per Candle.†	Total Output, Lumens.	Lumens per Watt.	Amperes at 120 Volts.	Amperes at 240 Volts.
105–125 volts	10	6.0	1.67	75	7.50	0.083	
	15	10.2	1.47	128	8.55	0.125	
	20	14.2	1.41	178	8.90	0.167	
	25	18.5	1.35	234	9.30	0.208	
	40	30.3	1.32	380	9.50	0.333	
	50	38.2	1.31	480	9.60	0.416	
	60	47.0	1.28	590	9.80	0.500	
	100	82.0	1.22	1030	10.30	0.833	
220–250 volts	25	15.2	1.65	191	7.60	......	0.104
	40	28.2	1.42	354	8.85	......	0.167
	60	43.2	1.39	540	9.05	......	0.250
	100	78.7	1.27	990	9.90	......	0.417
	150	118.0	1.27	1480	9.90	......	0.625
	250	208.0	1.20	2620	10.50	......	1.042

* Manufacturers' standard ratings, July 1, 1916.

† Based on mean spherical candlepower.

Rated life is 1000 hours for all lamps except the 10-watt size, which has a life of 1500 hours.

TABLE 3. (Par. 31)

DATA ON MAZDA C (GAS-FILLED) LAMPS FOR CONSTANT POTENTIAL CIRCUITS *

	Rated Watts.	Mean Spherical C.P.	Rating. Watts per Candle.†	Total Output, Lumens.	Lumens per Watt.	Amperes at 120 Volts.	Amperes at 240 Volts.
105–125 volts	75	69	1.09	865	11.5	0.625	
	100	100	1.00	1,260	12.6	0.833	
	200	222	0.90	2,800	14.0	1.67	
	300	366	0.82	4,600	15.3	2.50	
	400	488	0.82	6,150	15.3	3.33	
	500	641	0.78	8,050	16.1	4.17	
	750	1010	0.74	12,800	17.0	6.25	
	1000	1430	0.70	18,000	18.0	8.33	
220–250 volts	200	200	1.00	2,520	12.6	......	0.833
	300	326	0.92	4,100	13.7	......	1.25
	400	445	0.90	5,600	14.0	......	1.67
	500	588	0.85	7,400	14.8	......	2.08
	750	915	0.82	11,500	15.3	......	3.13
	1000	1280	0.78	16,100	16.1	......	4.17

* Manufacturers' standard ratings, July 1, 1916.
† Based on mean spherical candlepower.
Rated life is 1000 hours for all sizes.

TABLE 4. (Par. 47)

PERFORMANCE OF TYPICAL ENCLOSED CARBON ARC LAMPS

	SERIES.			MULTIPLE.					
	D.C.	A.C.	A.C.	D.C.	D.C.	D.C.	A.C.	A.C.	Intensified Arc, D.C.
Terminal voltage	75	77	77	110	110	220	110	110	110
Arc voltage.....	73	72	72	80	80	150	72	72	80
Amperes.......	6.6	6.6	7.5	5	6.5	3.25	6	7.5	5
Watts..........	495	425	480	550	715	715	430	540	550
Power factor....	....	0.84	0.84	....	....	....	0.65	0.65	
Electrode life, hrs.	125	125	100	150	100	150	125	100	75
M.L.H.C.P*....	479	232	291	379	559	215	276	371	414
Watts per M.L.H.C.P.*.	1.03	1.83	1.65	1.45	1.28	3.33	1.56	1.45	1.33
M.S.C.P.†......	290	144	173	215	318	160	160	215	225
Watts per M.S.C.P.† ...	1.71	2.95	2.77	2.56	2.25	4.44	2.68	2.51	2.44
Lumens........	3650	1810	2175	2700	4000	2010	2010	2700	2830
Lumens per watt	7.37	4.25	4.53	4.86	5.58	2.81	4.67	4.98	5.14
Reflector.......	Porcelain enameled steel			Porcelain					
Inner globe.....	Clear			Opal					
Outer globe.....	Clear			None					

* M.L.H.C.P. = mean lower hemispherical candlepower.
† M.S.C.P. = mean spherical candlepower.

TABLE 5. (Par. 52)

PERFORMANCE OF TYPICAL ENCLOSED, FLAME-ARC LAMPS

	Series.	Multiple.			
	A.C.	A.C.	A.C.	D.C.	D.C.
Terminal voltage.......	55	110	110	110	110
Arc voltage...........	49	48	48	70	70
Amperes..............	10	7.5	7.5	6.5	6.5
Watts.................	445	500	500	715	715
Power factor..........	0.81	0.61	0.61		
Electrode life, hours....	100	100	100	100	100
M.L.H.C.P.*..........	1400	1490	920	1320	1250
Watts per M.L.H.C.P.*.	0.32	0.34	0.54	0.54	0.57
M.S.C.P.†	769	850	695	797	625
Watts per M.S.C.P.† ...	0.58	0.59	0.72	0.90	1.14
Lumens...............	9670	10,680	8740	10,010	7860
Lumens per watt.......	21.70	21.4	17.44	14.02	11.0
Reflector.............	None	None	None	None	Steel
Inner globe............	Clear	Clear	Clear	Clear	Clear
Outer globe...........	Clear	Clear	Translucent	Translucent	None

White-light carbons used. Yellow-light carbons give about 25 per cent more light.

* M.L.H.C.P. = mean lower hemispherical candlepower.
† M.S.C.P. = mean spherical candlepower.

TABLE 6. (Par. 56)

Performance of Typical Metallic-electrode, Series Arc Lamps

	Standard Electrodes.			High Efficiency Electrodes.			
	Pendant Type.		Ornamental Type.	Pendant Type.			Ornamental Type.
Terminal voltage......	75–80	75–80	80	75–80	75–80	75–80	80
Arc voltage..........	74–79	74–79	79	74–79	74–79	74–79	79
Amperes.............	4	6.6	5	4	5	6.6	5
Watts................	310	510	400	310	388	510	400
Electrode life, hours...	350	125	.....	150	120		
M.L.H.C.P.*.........	488	1266	510	741	1131	1626	510
Watts per M.L.H.C.P.*	0.63	0.403	0.78	0.42	0.34	0.314	0.52
M.S.C.P.†...........	256	668	418	425	637	948	631
Watts per M.S.C.P.† ..	1.21	0.76	0.96	0.73	0.61	0.54	0.63
Lumens..............	3220	8400	5250	5340	8000	11,900	7940
Lumens per watt......	10.40	16.50	13.1	17.2	20.6	23.40	19.8

* M.L.H.C.P. = mean lower hemispherical candlepower.

† M.S.C.P. = mean spherical candlepower.

All pendant lamps have clear globes; ornamental lamp has translucent globe.

Pendant lamps with standard electrodes have internal reflector; with high efficiency electrodes, lamps have refractor. (See Fig. 9.)

TABLE 7. (Par. 60)

Performance Data for Typical Cooper Hewitt Mercury Vapor Lamps *

Type of Lamp.	Current.	Tube Material.	Tube Length, Inches.	Method of Lighting.	Amperes.	Volts.	Average Watts.	Initial Lower Hemispherical Candlepower.	Initial Watts per Lower Hemispherical Candlepower.	Initial Spherical Candlepower without Reflector.	Initial Watts per Spherical Candlepower without Reflector.
H	D.C.	Glass	21	Auto-tilting	3.5	100–125†	192	300	0.64	190	1.01
P	D.C.	Glass	50	Shifter	3.5	100–125	385	800	0.48	500	0.77
K	D.C.	Glass	45	Hand-tilting	3.5	100–125	385	700	0.55	440	0.87
L	D.C.	Glass	35	Shifter	2.1	100–125	220	400	0.55	250	0.88
F‡	A.C.	Glass	50	Shifter	4.1	100–125	380	800	0.48	500	0.77
E‡	A.C.	Glass	35	Shifter	2	100–125	200	400	0.5	250	0.80
Z	D.C.	Quartz	4	Auto-tilting	3.3	200–240	726	2400	0.3	1500	0.48

* Data supplied by Cooper Hewitt Electric Co.
† Two in series on this voltage.
‡ Power factor 87 per cent.

All above are low-pressure types except Type "Z."

TABLE 8. (Par. 118)

Illumination Intensities for Commercial Lighting

Explanation.—**Column 2** indicates method of illumination most suitable. G = general (uniform) illumination. L = localized lighting, L–G = group lighting (non-uniform general illumination), G & L = combined local and general lighting. **Column 3** gives the system of illumination most commonly used. Where two are given, the first is usually employed. D = direct system, SI = semi-indirect, I = indirect. **Column 4** gives average value of foot-candles intensity or the lumens per square foot required. (See foot-note at end of table.)

1 Class of Service.	2 Meth. of Illum.	3 System of Illum.	4 Foot-candles.	5 Reflector Equipment.
Armory	G	D	2.0– 3.0	Metal or prismatic glass
Assembly room	G	D, SI, I	0.5– 1.5	Prismatic or white glass
Auditorium	G	D, SI, I	1.0– 3.0	Prismatic or white glass
Automobile show-room	G	SI, D	3.0– 6.0	Prismatic or white glass
Ball room	G	D, SI	2.0– 5.0	White glass or bare frosted lamps
Bank (general)	G	SI, D	2.0– 3.0	White glass
Bank (desk work)	G & L	SI, D	4.0– 8.0	Same general lighting with desk lamps
Barber shop	G	SI, I, D	3.0– 5.0	White glass or prismatic Mirror refl. for I
Billiard room (gen.)	G	D	0.8– 1.5	Prismatic or white glass
Billiard room (table)	L	D	6.0–10.0	Prismatic glass or metal
Bowling (alley)	L–G	D	1.5	Eight metal, angle refl. with 40-watt lamps
Bowling (pins)	L–G	D	4.0– 6.5	Angle refl. in front of pins, 40-watt lamp
Café (general only)	G	SI, D	2.0– 4.0	White glass or prismatic
Café (with table lamps)	G & L	SI	1.0– 2.0	White glass or prismatic, opaque shades on table lamps
Card room	G	D	2.0– 3.5	Prismatic or white glass
Church	G	SI, I, D	1.0– 3.0	White glass. Mirror refl. for I
Corridors	G	D, SI	0.5– 1.5	White glass or prismatic enclosing globes
Court room	G	D	2.0– 4.0	White glass or prismatic
Desk	L	D	4.0– 6.0	Metal reflector, enclosing lamp
Garage	G & L	D	1.0– 3.0	Metal or prismatic. Hand lamps

TABLE 8—*Continued*

1 Class of Service.	2 Meth. of Illum.	3 System of Illum.	4 Foot-candles	5 Reflector Equipment.
Gymnasium	G	D	2.5– 4.0	Metal or prismatic. Hand lamps
Hospital:				
Ward (dim)	G	SI, I	0.2– 0.3	White glass or mirror Dim light used during sleeping period
Ward (bright)	G	SI, I	1.0– 2.0	
Operating table	L–G	D	25 or more	White glass angle reflectors
Hotel:				
Bedroom	G & L	SI, D	1.5–3.0	White glass or prismatic. Wall brackets near dresser. Table lamp
Dining room	G	SI, D	2.0–4.0	White glass or prismatic
Dining room	G & L	SI	1.0–2.0	White glass or prismatic. Table lamps with opaque shades
Lobby	G	SI, D	2.0–4.0	White glass or prismatic
Library:				
Stack room	L–G	D	1.5–2.0	Prismatic or white glass
Reading room	G	SI	3.0–4.0	White glass
Reading room	G & L	SI, D	1.0–1.5	White glass or prismatic. Table lamps with opaque reflectors
Office:				
Small (private)	G	SI, D	1.0–2.0	White glass or prismatic, with desk lamp
Large	G	SI, D	4.0–8.0	White glass or prismatic
Large	G & L	SI, D	1.5–2.0	White glass or prismatic, with 40-watt bowl frosted lamp and metal refl. for desk
Public spaces	....	......	0.5–1.5	Glass or metal
Reading, clear print	....	......	1.0–1.5	
Reading, newspaper	....	......	2.0–3.0	
Residence.				
Hall	G	SI, D	0.7–1.0	White glass
Parlor or living room	G	SI, D	1.0–3.0	White glass. May be supplemented by table lamp
Library	G	SI, D	2.0–4.0	
Dining room	G	SI, D	1.0–3.0	White glass
Kitchen	G	D	2.0–3.0	White glass or prismatic.
Bedroom	G & L	SI, D	1.0–3.0	White glass. Wall brackets near dresser
Storeroom	G	D	0.4–0.8	Prismatic or bare lamp

TABLE 8—*Continued*

1 Class of Service.	2 Meth. of Illum.	3 System of Illum.	4 Foot-candles.	5 Reflector Equipment.
Restaurant	....	......	....	See hotel dining room
Saloon	G	D, SI	2.0–4.0	Prismatic or white glass
School:				
Classroom	G	SI, D	3.5–5.0	White glass or prismatic
Laboratory	G	D, SI	3.0–5.0	White glass or prismatic
Store:				
Clothing	G	SI, D	4.0–7.0	White glass or prismatic
Dry goods	G	SI, D	4.0–7.0	White glass or prismatic
Furniture	G	SI, D	3.0–6.0	White glass or prismatic
Grocery	G	D, SI	2.0–4.0	White glass or prismatic
Hardware	G	D	3.0–5.0	White glass or prismatic
Jewelry	G, G & L	D, SI	4.0–6.0	White glass or prismatic. With direct units over the counters
Millinery	G	SI, D	4.0–6.0	White glass or prismatic. (Color matching unit desirable)
Shoe	G	SI, D	2.0–4.0	White glass or prismatic
Stationery	G	SI, D	2.0–4.0	White glass or prismatic
Tobacco	G	D, SI	2.0–4.0	White glass or prismatic
Show window:				
High grade	G	D	15–30	Glass or metal, angle reflec.
Ordinary	G	D	10–20	Glass or metal. Angle or symmetrical
Small town	G	D	5–15	Glass or metal
Stable	G	D	0.8–1.0	Glass or metal
Theatre:				
Auditorium	G	D	1.0–3.5	White glass or prismatic
Moving picture	G	D, SI	0.2–0.5	White glass or prismatic (during exhibition)
Moving picture	G	D, SI	2.0–2.5	White glass or prismatic (during intermission)

Values of foot-candles for (G) are average over entire room, for (G & L) value is the illumination produced by G. Illumination on work in this case is higher due to L. Where L–G is specified, the value is illumination on work. The average value in this case will be somewhat lower.

Col. 4 from data published by Holophane Works of General Electric Co. and National X-ray Reflector Co.

TABLE 9. (Par. 118)

Illumination Intensities for Industrial Lighting *

Explanation.—**Column 2** indicates method of illumination most suitable. G = general (uniform) illumination, L = localized lighting, L–G = group lighting (non-uniform general illumination), G & L = combined local and general lighting.

Column 3 gives average value of foot-candles intensity or the lumens per square foot required. (See foot-note at end of table.)

All illumination by the direct system unless otherwise noted.

1 Class of service.	2 Method of Illum.	3 Foot-candles.	4 Remarks.
Bakeries	G	2–3	Prismatic or steel reflectors.
Bench work:			
Single benches	L–G, G	3–5 for rough work	40 to 100-watt lamps, spaced 6 to 10 feet
Single benches at wall	G, L–G		
Double benches	G, L-G	5–10 for fine work	60 to 150-watt lamps, spaced 8 to 12 feet
Book binding:			
Folding, assembling pasting	G	2–3	Steel or prismatic glass refl.
Cutting, punching, stitching	G	3–5	Steel or prismatic glass refl.
Embossing	G	4–6	Steel or prismatic glass refl.
Candy factory	G	2–4	Steel or prismatic glass refl.
Canning factory	G, L–G	1.0–2.5	See bench work
Carpenter shop	......	....	See wood-working
Clothing mfg.:			Prismatic or steel. G of 1.0–1.5 foot-candles
Cutting, pressing	L–G	5–10	See bench work
Machine sewing, dark goods	G & L	10–15	15-watt lamp with metal refl. for each machine
Machine sewing, light goods	G & L	4–6	10-watt lamp with metal refl. for each machine
Hand sewing, dark goods	G	6–8	
Hand sewing, light goods	G	4–6	
Inspecting	L–G	6–10	See bench work

Values in column 3 are for illumination on the work unless otherwise stated.

* From data published in Handbook of Incandescent Lighting, General Electric Co.

TABLE 9—*Continued*

1 Class of Service.	2 Method of Illum.	3 Foot-candles.	4 Remarks.
Cotton mill:	......	....	Steel reflectors
Receiving and opening bales..............	G	0.8–1.5	
Opening and lapping..	L–G	1–2	One 40-w. lamp at each end of machine
Carding.............	L–G	1.5–2.5	One 40-w. lamp per machine staggered front and back.
Drawing frame.......	L–G	1.5–2.5	Two 40-w. lamps per machine
Roving frame........	L–G	2–3	Two 40-w. lamps per machine over aisle
Ring spinning, spooling, etc............	L–G	2–3	Two 60-watt lamps over aisle, spaced every 100 spindles
Slashing.............	L–G	1–2	Two 40-watt lamps per machine over aisle
Warpers.............	L–G, G	2–3.5	One 60-watt lamp over beam and one over rack
Weaving, light goods..	L–G	2–4	One 60-w. for 4 mach. in aisle
Weaving, dark goods..	L–G	3–5	One 100-w. lamp for 4 machines in aisle.
Dyeing..............	L–G	2–3	
Dyeing, inspecting....	L–G	15–30	Special color-matching unit
Inspection...........	L–G	5–10	One 60-watt lamp over each table, with G
Dairies and milk depots..	G, L–G	1–4	Enamel steel reflectors
Drafting room.........	G. L–G	6–12	Indirect, semi-indirect or direct lighting may be used. Mirror reflectors for I, glass reflectors for other systems
Engraving............	L	10–15	Steel reflectors
Factory...............	....	....	Steel or prismatic glass refl.
General with local ltg..	G & L	1.0–2	
General, no local ltg..	G	3–6	
Forge and blacksmith shop...............	G, L–G	2–4	Enamel steel reflectors
Foundry.............	......	....	Enamel steel reflectors
Moulding, machine...	L–G	1–3	40 to 100-watt lamps with portable lamps
Moulding, floor......	G & L	1–2	
Core making.........	L–G	1–3	See bench work
Cupola, firing floor...	G	1–2	
Cleaning............	G	1–2	

TABLE 9—*Continued*

1 Class of Service.	2 Method of Illum.	3 Foot-candles.	4 Remarks.
Glove factory	......	....	Prismatic or steel ref'l. Approximately white light req'rd
Sorting	L–G	6–10	See bench work
Cutting, trimming, inspecting	L–G	5–6	See bench work
Sewing	G & L	8–12	See clothing mfg.
Knitting mill	......	....	Steel reflectors
Ordinary knitting	L–G	2–4	One 60-watt lamp for 4 mach.
Flat knitters	L–G	3–5	60-watt lamps in aisle; 6 to 8-foot centres
Looping, seaming and finishing	G	4–6	For general work
	L	....	For fine work. 20-watt lamp for each machine
Napper machines	L–G	2–3	40-watt lamp each machine over front rolls.
Inspecting	L–G	3–6	
Laundry	G	3–5	Steel or prismatic reflectors
Machine shops	......	....	Enamel steel reflectors
Bench work, fine	L–G, L	5–10	See bench work
Bench work, rough	L–G	3–5	
Machine tools, fine work	G, L–G	5–8	
Machine tools, coarse work	G, L–G	3–5	
Buffing and grinding	L–G	2–4	
Assembling and erect'g	L–G	1–3	
Inspecting	G	4–7	Supplemented by local units as needed.
Offices	......	....	See commercial lighting, Tab. 8
Packing and shipping	......	....	Steel or prismatic reflectors
Fine work	G, L–G	3–5	See bench work
Ordinary work	G	1.5–2.5	See bench work
Painting and finishing	......	....	Steel reflectors
Automobile, furniture, etc. Fine work	G	4–8	
Ditto, coarse work	G	2–4	
Paint and ink works	G	2–4	Steel reflectors
Pottery	......	....	Steel reflectors
Grinding	G	1–2	
Moulding, cleaning and trimming	L–G, G	2–4	
Inspecting	G, L–G	4–6	

TABLE 9—*Continued*

1 Class of Service.	2 Method of Illum.	3 Foot-candles.	4 Remarks.
Power house...........	......	....	Steel or prismatic reflectors
Engine room.........	G & L	2–3	
Boiler room..........	G & L	0.8–1.5	
Printing...............	......	....	Prismatic or steel reflectors
Linotype and monotype	G & L	5–10	2 foot-candles for G with 25-watt local lamps
Typesetting..........	G & L	6–8	2 f-c. for G with 40-w. lamps every 4 ft. of type tray
Matrixing and casting.	G	2–4	
Presses..............	L–G	3–5	One or more 60-watt lamps.
Cutting and folding..	G, L–G	2–4	
Sheet metal shop.......	......	....	Steel reflectors
Punching, stamping...	G	2–5	Dome or angle reflectors
Cutting, shearing and spinning...........	G, L–G	3–5	
Polishing and finishing.	G, L–G	2–4	
Shipping room.........	......	....	See packing and shipping
Shoe shop.............	......	....	Steel or prismatic refl., with G of 1 to 1.5 foot-candles
Inspecting and sorting	L–G	7–9	60-watt lamps each position
Cutting............	L–G, G	5–7	40-watt lamps on 5-ft. centres
Stitching (machine)...	G & L	6–8	25-watt lamp in angle refl.
Lasting and welting...	L, L–G	4–6	40-watt lamp each machine
Silk mill...............	......	....	Steel reflectors
Winding frames......	L–G	2–4	Three 60-watt lamps per frame
Throwing frames.....	L–G	2–4	60-watt lamps in aisle, spaced 8 to 10-ft. centres
Quilling............	L–G	3–5	60-watt lamps in aisle spaced 5 to 7 ft. centres
Warping...........	L–G	3–5	A 60-watt lamp over creel, reed and reel
Weaving...........	L–G	4–6	60-watt lamp over loom, 60-watt lamp in rear alley
Dyeing..............	L–G	2–3	
Dyeing, inspection....	L	15–40	Special color-matching unit
Finishing...........	L & G	3–5	60-watt lamp over each table
Steel works............	......	....	Steel reflectors
Unloading yards, open hearth floors, cast houses, ore yards...	G	0.1–0.3	Radial wave or dome refl.
Loading yards........	G	0.3–0.5	Radial wave or dome refl.

TABLE 9—*Continued*

1 Class of Service.	2 Method of Illum.	3 Foot-candles.	4 Remarks
Steel Works:			
Rolling mills.........	G	1–3	Dome or angle refl.
Wire drawing........	G	2–8	High value for fine work
Stock rooms(open rooms)	......	....	Steel or prismatic refl.
Rough material......	G	0.5–1.0	
Fine material........	G	0.5–3.0	
Warehouses............	G	0.5–1.0	Steel reflectors
Woodworking..........	......	....	Steel reflectors
Rough work.........	G	2–4	
Fine work...........	G	4–6	
Woolen mill...........	......	....	Steel reflectors
Receiving and picking.	G	2–4	
Washing and combing.	G	3–4	
Carding.............	L–G	2–3	60-watt lamp in aisle, every two machines
Twisting............	L–G	2–3	40-watt lamp in aisle, spaced on 7 to 10 ft. centres
Dyeing..............	L–G	2–3	60-watt lamp every other tank
Dyeing, inspecting....	L	15–35	Special color matching unit
Warping............	L–G	3–5	60-watt lamp over reel and reed
Weaving light goods..	L–G	4–6	60-w. lamp over lay, 40-w. lamp in each aisle. For goods wider than 36 in. use two 40-w. lamps over loom and one 60-w. in each aisle. For dark goods use next larger size lamp
Weaving, dark goods..	L–G	6–8	
Perching............	L–G	8–15	100-w. lamp over each frame
Perching, dark goods..	L–G	10–20	150-w. lamp over each frame

TABLE 10. (Par. 120)

Utilization Efficiencies for Tungsten Lamps *

These constants are the percentage of the total light flux produced by a tungsten lamp which is useful in producing illumination on a horizontal plane.

Reflector Equipment.	Color of Ceiling.†	Light.	Light.	Light.	Medium.	Medium.	Dark.
	Color of Walls.†	Light.	Medium.	Dark.	Medium.	Dark.	Dark.
Prismatic glass reflectors (velvet finish) ‡		0.53	0.50	0.45	0.45	0.42	0.38
Prismatic glass enclosing globes		0.51	0.47	0.44	0.43	0.38	0.35
Translucent glass reflectors		0.49	0.44	0.41	0.40	0.37	0.34
Steel reflectors (enamel or aluminum finish)		0.48	0.46	0.44	0.45	0.44	0.44
Mirror reflectors (direct system)		0.60	0.53	0.48	0.48	0.45	0.40
Translucent glass enclosing globes		0.34	0.31	0.28	0.26	0.24	0.19
Semi-indirect bowls		0.40	0.37	0.33	0.25	0.20	
Indirect—steel reflectors		0.31	0.28	0.25	0.18	0.15	
Indirect—mirror reflectors		0.35	0.33	0.30	0.20	0.17	
Bare lamp		0.41	0.35	0.30	0.30	0.25	0.21

* Based on data published by Nat. Elec. Light Ass'n, 1916, and Lighting Handbook published by Holophane Works, of General Elec. Co., 1915.

† For classification of terms—light, medium and dark, see Table 11.

‡ For clear reflectors or for velvet finish with gas-filled lamps, use values for mirror reflectors, direct system.

Note. The values given above apply to rooms having 200 to 1000 sq.ft. area. For rooms smaller than 200 sq.ft., the effect of reflection from the walls becomes important and the values should be reduced 10 to 40 per cent. The greatest reduction should be made for dark walls or very small rooms, since in these cases considerable light strikes the walls and never reaches the working plane. For rooms larger than 1000 sq.ft. the values can be increased somewhat (not more than 15 per cent) particularly for medium or dark walls. Where the area to be illuminated forms a part of a larger area, and no appreciable light reaches the part under consideration from the remainder of the room, the values for dark walls should be used. If the ceiling of the room is made up of skylights, use the values for dark ceiling.

TABLE 11. (Par. 120)

Color Classification of Walls and Ceilings

Light.	Medium.	Dark.
White	Medium light buff	Light brown
Cream	Faint pink	Light blue
Very light buff	Light green	Tan
Light orange yellow	Light gray	Medium green
	Bluish white	Light red
	Pale gray	

TABLE 12. (Par. 120)

Power Required to Produce One Foot-candle Illumination

Tungsten lamps,* uniform lighting.

Reflector Equipment.		Watts per Square Foot					
	Color of Ceiling.†	Light.	Light.	Light.	Medium.	Medium.	Dark.
	Color of Walls.†	Light.	Medium.	Dark.	Medium.	Dark.	Dark.
Prismatic glass reflectors (velvet finish) ‡		0.193	0.204	0.227	0.227	0.243	0.269
Prismatic glass enclosing globes		0.200	0.217	0.232	0.237	0.269	0.291
Translucent glass reflectors		0.208	0.232	0.249	0.245	0.276	0.300
Steel reflectors (enamel or aluminum finish)		0.213	0.222	0.232	0.227	0.232	0.232
Mirror reflectors (direct system)		0.170	0.193	0.213	0.213	0.227	0.255
Translucent glass enclosing globes		0.300	0.329	0.365	0.392	0.425	0.537
Semi-indirect bowls		0.255	0.276	0.310	0.410	0.510	
Indirect—steel reflectors		0.329	0.365	0.408	0.567	0.680	
Indirect—mirror reflectors		0.291	0.309	0.340	0.510	0.600	
Bare lamp		0.249	0.291	0.340	0.340	0.408	0.485

* Values are correct for 60-watt vacuum-type lamps (Mazda B) operating at 1.28 w. per m.s.cp. and giving 9.8 lumens per watt. Smaller lamps have slightly higher and larger lamps slightly lower values. For gas-filled lamps (Mazda C) multiply by 0.64. This is correct for 300 or 400-w. lamps. Other sizes give slightly higher or lower values. Values are based on the utilization efficiency given in Table 10 and are for rooms of 200 to 1000 sq.ft. area. The corrections are opposite from those given in Table 10, i.e., the values should be *increased* for smaller rooms and *decreased* for larger rooms.

† For classification of terms—light, medium and dark, see Table 11.

‡ For clear reflectors or for velvet finish with gas-filled lamps use values for mirror reflectors, direct system.

TABLE 13. (Par. 120)

POWER REQUIRED FOR TUNGSTEN LIGHTING SYSTEMS

Watts per square foot for uniform illumination

Service.	Foot-candles.	With Vacuum Type Lamps.*			With Gas-filled Lamps.*		
		Direct.	Semi-Indirect.	Indirect.	Direct.	Semi-Indirect.	Indirect.
Auditorium	2	0.47†	0.69	0.77	0.30†	0.44	0.50
Corridors and halls	1	0.24†	0.33	....	0.15†	0.21	
Drafting rooms	10	2.40	3.30	4.00	1.54	2.10	2.56
Engraving	12	2.80	....	....	1.80		
Factory, coarse work	2	0.59	....	....	0.38		
Factory, fine work	5	1.33	....	....	0.85†		
Factory, inspecting	10	2.66	....	....	1.70‡		
Gymnasium	3	0.72†	....	....	0.46†		
Hospital (ward)	1.5	....	0.50	0.56	....	0.32	0.36
Hotel (bedroom)	2.5	0.64	0.83	0.93	....	0.53	0.60
Library (reading room)	4.0	1.00	1.40	1.55	0.64†	0.90	1.00
Office, general	4.0	1.00	1.40	1.55	0.64†	0.90	1.00
Office, special	8.0	2.00	2.80	3.10	1.28†	1.80	2.00
Packing and shipping coarse work	2	0.51	....	....	0.33		
Packing and shipping fine work	4	1.00	....	....	0.64		
Power house, engine room	2.5	0.69	....	....	0.44		
Power house, boiler room	1.0	0.30	....	....	0.19		
Residence	2.0	0.48	0.64	0.74	....	0.41	0.48
Restaurant	3.0	0.72†	1.00	1.11	0.46†	0.64	0.71
School	4.0	1.00	1.40	1.55	0.64†	0.90	1.00
Store	5.0	1.25	1.75	1.95	0.80†	1.13	1.25
Storage	0.5	0.14	....	....	0.09		
Warehouses, piers, etc.	0.75	0.21	....	....	0.13		

* In these columns allowance has been made for dust.

† If glass enclosing globes are used, multiply by 1.5.

‡ When special color matching units are used, double this figure.

NOTE. The values given above are for usual conditions as regards color of walls and ceilings and size of room. If walls and ceiling are unusually dark, increase the values 10 to 15 per cent.

TABLE 14. (Par. 121)

POWER REQUIRED FOR FLAME-ARC LIGHTING SYSTEMS

Class of Service.	Watts per Square Foot.	Height above Floor, Feet.
Forge and blacksmith shops	0.35	30–40
Foundries	0.45	30–40
Machine shops, large tools	0.40	20–30
Piers (closed)	0.15	25
Power houses, engine room	0.35	30–40
Steel mills	0.20 to 0.35	30

Above figures allow for deprcciation due to dust.

TABLE 15. (Par. 123)

SIZES OF LIGHTING UNITS FOR VARIOUS MOUNTING HEIGHTS

(Direct Illumination)

Height of Ceiling.	Size of Unit, Watts.			
	Tungsten Vacuum Type.	Tungsten Gas-filled Type.	Mercury-vapor Lamp.*	Flame-arc Lamp.
Up to 9 ft.	40, 50, 60	not used	200	not used
9–11 ft.	60 or 100	75 or 100	200 or 400	not used
11–16 ft.	100	100 or 200	400	not used
16–20 ft.	100	200 or 300	400 or 725	all sizes
20 ft. and above.	100	300 to 1000	400 or 725	all sizes

* 200-watt lamp is 20-inch lamp, low-pressure type; 400-watt lamp is 50-inch lamp, low-pressure type; 725-watt lamp is quartz lamp. This is seldom used where it must be mounted lower than 18 feet.

TABLE 16. (Par. 121)

POWER REQUIRED FOR LIGHTING WITH COOPER HEWITT LAMPS *

(Low-pressure type) †

Class of Service.	Watts per Sq.ft.	Height above Floor.
Clothing Mfg:		
Cutters	1.72	10
Hand sewing	0.74	10
Pressing	1.65	10
Cotton Mills:		
Preparing thread	0.65	10–12
Weaving coarse goods	0.45	10–15
Weaving fine goods	0.70	10–14
Finishing	0.64	12
Embroidery plants	1.50	10–15
Forge and blacksmithing shops	0.40–0.70	10–20
Foundries:		
Moulding	0.25–0.50	15–25
Casting	0.25–0.50	15–25
Cleaning	0.30	10–20
Glass Mfg.:		
Cutting	0.85	12
Inspection	1.30–2.00	10–12
Polishing and grinding	0.70	20
Machine shops:		
Small tools	0.90	10–15
Large tools	0.45–0.60	20–50
Punch presses	0.75	12–35
Grinding and polishing	0.75	9–14
Boiler shops	0.35–0.50	20–35
Assembling and erecting	0.30–0.80	10–50
Inspection	0.85	10–12
Printing plants:		
Composition (hand)	1.75	10–12
Sterotyping	0.75	10–12
Press rooms	1.00	10–15
Power houses:		
Boiler rooms	0.50	16–40
Turbine rooms	0.35	15–75
Shipping and storage	0.25	8–12
Silk mills:		
Preparing thread	0.70–1.00	8–12
Weaving	1.00–1.25	8–14
Finishing	1.50	10–12
Varnishing	0.80	8–10
Finishing automobile bodies	2.00–2.50	8–10
Wood working	0.35–0.90	8–15

* From data published by W. A. D. Evans, Proc. Illum. Eng. Soc., Sept., 1915.

† Quartz lamps would give same illumination with about 75 per cent of power required for low-pressure lamps.

TABLE 17.* (Par. 125)

Desirable Spacing for Direct Lighting Units

Class of Service.	Ceiling Height, Feet.	Spacing of Unit, Feet.
1. Armories, auditoriums, churches, public halls, restaurants, ball rooms, theatres, etc..	12–16 over 16	12–16 15–26
2. Factories: Ordinary work	8–11 11–15 over 15	8–11 10–16 14–22
3. Factories: Close work.	8–11 11–15 over 15	6–10 8–13 11–17
4. Offices, libraries, school rooms:		
(Where desk lamps are used)	10–20	12–18
(Where no desk lamps are used)	9–12	7–11
(Where no desk lamps are used)	12–16	9–14
(Where no desk lamps are used)	over 16	11–18
5. Stores:	8–11 11–15 over 15	8–11 10–16 14–22
6. Drafting rooms:		
(Where desk lamps are used)	10–20	12–18
(Where no desk lamps are used)	9–12	6– 8
(Where no desk lamps are used)	12–16	8–10
(Where no desk lamps are used)	over 16	10–15

* Based on data published by Holophane Works of G. E. Co.

Note. It is not desirable to use the widest spacing on the smallest ceiling height.

TABLE 18. (Par. 125)

Desirable Spacing for Indirect and Semi-indirect Lighting Units *

Class of Service.	Ceiling Height, Feet.	Spacing of Unit, Feet.	Hanging Height, Feet.†
1. Offices, libraries, school rooms, stores, banks	8	12	1.5
	10	15	2.0–2.5
	12	18	2.5–3.0
	14	24	3.5–4.0
	16	28	3.5–4.5
	18	36	4.0–5.0
	20	40	5.0–6
2. Drafting rooms, operating rooms, sewing machine rooms	8	6	1.5
	10	7.5	2.0–4
	12	9.0	3
	14	14.0	3.5–4.0
	16	16	4.0–5.0
	18	18	4.0–5.5
	20	20	5.5–6

* From data published by National X-Ray Reflector Co. Values are maximum and should not be exceeded. † Distance from ceiling to top of reflector.

TABLE 19. (Par. 135)

Illumination Intensities for Street Lighting *

Class of Streets.	Average Illumination Intensity, Ft.-candles	Desirable Characteristic.
Important avenues and heavy traffic streets	0.5–1.0	Ample light on building fronts
Secondary business streets	0.1–0.2	Ample light on building fronts
City residence streets	0.05–0.1	Subdued light on building fronts
Suburban highways.	0.01–0.02	Maximum light on roadway
Suburban residence streets	0.005–0.015	Very subdued light on building fronts

* From National Electric Light Assn., Report of Committee on Street Lighting, 1916.

Note. Bright moonlight has an intensity of about 0.03 foot-candle.

TABLE 20. (Par. 165)

Temperature Ratings and Overloads of Motors *

Motor.	Temperature Rise, Degrees Centigrade.								
	Continuous Duty.						Short-time Duty. ‡		
	Full Load.		Overload.			Momentary Overload Per cent.	Full Load.		Momentary Overload Per cent.
	A	B	Sustained.	A	B		A	B	
Direct current, open type: †									
Small (up to ¼ h.p.)...	40	40							
Medium (¼ to 1 h.p.)	40	45	25%–1 hr.	55	60	50	55 §	60 §	
Large (above 1 h.p.).	40	45	25%–2 hr.	55	60	50	55 §	60 §	
Direct current, protected type:									
Medium............	50	55	....	...	...	50	55 §	60 §	
Large..............	50	55	....	...	...	50	55 §	60 §	
Direct current, enclosed type:									
Small..............	55	55							
Medium............	55	60‖	....	...	...	50	55 §	60 §	
Large..............	55	60‖	....	...	...	50	50 §	60 §	
Induction, open type:									
Small..............	40								
Medium............	40	...	25%–1 hr.	55	...	50	55	...	50
Large..............	40	...	25%–2 hr.	55	...	50	55	...	50
Induc., enclosed type:									
Small..............	55								
Medium and large...	55	...	....	...	...	50	55	...	50

* Based on ratings adopted by the Electric Power Club, an association of the principal manufacturers of motors.

Column A = temperature rise for all parts except commutator.

Column B = temperature rise for commutator.

† For this type of motor another rating is also used, giving 50 deg. Cent. rise with no overload guarantees.

‡ The temperature rise for short-time duty is generally based upon carrying full load for two hours. For crane service the time is one-half hour. Other ratings are used for special purposes.

§ For special non-combustible insulations A = 75, B = 80.

‖ For constant speed; 55 for adjustable and varying speed motors.

TABLE 21. (Par. 167)

CURRENT AND SIZE OF WIRE FOR DIRECT CURRENT MOTORS

Horse-power.	Amperes at Full Load.			Size of Wire.*					
				Rubber Insulation.			Other Insulation.		
	115 Volts.	230 Volts.	550 Volts.	115 Volts.	230 Volts.	550 Volts.	115 Volts.	230 Volts.	550 Volts
0.5	5	2.5	1.1	14	14	14	14	14	14
1	8.8	4.4	1.8	14	14	14	14	14	14
2	16	8	3.4	12	14	14	14	14	14
3	24	12	5	8	12	14	8	12	14
5	40	20	8.4	5	8	14	6	10	14
7.5	58	29	12.1	3	6	12	5	8	14
10	76	38	15.9	1	6	12	3	8	12
15	112	56	23.4	00	4	8	1	6	10
20	146	73	30.5	0,000	1	6	0	3	8
25	182	91	38.1	250,000	0	6	000	2	8
30	216	108	45.2	350,000	00	4	000	1	6
35	252	126	52.6	400,000	000	4	0,000	0	6
40	288	144	60.2	500,000	0,000	3	300,000	0	5
50	356	178	74.4	600,000	0,000	1	350,000	00	3
60	428	214	89.5	800,000	350,000	0	500,000	000	2
75	532	266	111	1,100,000	450,000	00	600,000	250,000	1
100	710	355	148	1,700,000	600,000	0,000	900,000	350,000	0
125	886	443	185	Two 850,000	850,000	300,000	1,200,000	500,000	00
150	1076	538	224	Two 1,100,000	1,100,000	400,000	1,600,000	700,000	0000

* Allows at least 25 per cent overload.

TABLE 22. (Par. 167)

CURRENT AND SIZE OF WIRE FOR THREE-PHASE INDUCTION MOTORS

Horse-power.	Amperes, Full Load.				Size of Wire.† Rubber or Other Insulation.			
	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.
0.5*	3.6	1.8	0.9	0.7	14	14	14	14
1.0*	6.4	3.2	1.6	1.3	12	14	14	14
2.0*	11.6	5.8	2.9	2.3	8	14	14	14
3.0*	16.4	8.2	.4.1	3.3	8	10	14	14
5.0	26.8	13.4	6.7	5.4	6	8	12	14
7.5	39.2	19.6	9.8	7.9	3	8	12	12
10.0	53.2	26.6	13.3	10.7	1	6	8	10
15.0	77.0	38.6	19.3	15.5	00	3	8	8
20.0	109.0	54.6	27.3	21.8	000	1	6	6
25.0	125.0	62.6	31.3	25.1	0,000	0	5	6
35.0	.....	85.6	42.8	34.3	......	00	2	4
50.0	.....	122.0	61.0	48.6	......	0,000	0	1
75.0	.....	179.0	89.0	72.0	......	350,000	00	0
100.0	.....	237.0	118.0	95.0	......	500,000	0,000	000
150.0	.....	353.0	176.0	141.0	......	two 400,000	400,000	300,000
200.0	.....	451.0	226.0	181.0	......	two 500,000	500,000	400,000
250.0	.....	560.0	280.0	224.0	......	two 700,000	700,000	500,000
300.0	.....	670.0	335.0	268.0	......	two 900,000	900,000	600,000

* These motors are thrown directly on the line; all others are provided with auto-starters set to give a starting torque equal to full-load running torque.

† Sizes of wire are for squirrel-cage motors. For slip-ring motors, smaller sizes can be used. See paragraph 331.

TABLE 23. (Par. 167)

Current and Size of Wire for Two-phase Induction Motors

Horse-power.	Amperes, Full Load. †				Size of Wire ‡ Rubber or Other Insulation.			
	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.
0.5*	3.2	1.6	0.8	0.6	14	14	14	14
1.0*	5.6	2.8	1.4	1.1	14	14	14	14
2.0*	10.0	5.0	2.5	2.0	10	14	14	14
3.0*	14.4	7.2	3.6	2.9	8	12	14	14
5.0	23.2	11.6	5.8	4.7	6	8	12	14
7.5	34.0	17.0	8.5	6.8	4	8	12	12
10.0	46.0	23.0	11.5	9.2	2	6	10	10
15.0	66.8	33.4	16.7	13.4	0	4	8	8
20.0	94.4	47.2	23.6	18.9	000	2	6	8
25.0	108.4	54.2	27.1	21.7	000	1	5	6
35.0	.....	74.2	37.1	29.7	......	0	3	5
50.0	.....	105.0	52.6	42.1	......	000	1	2
75.0	.....	155.0	77.3	61.9	......	300,000	0	1
100.0	.....	205.0	103.0	82.0	......	450,000	000	00
150.0	.....	306.0	153.0	123.0	......	two 300,000	300,000	0,000
200.0	.....	390.0	195.0	156.0	......	two 400,000	400,000	300,000
250.0	.....	484.0	242.0	194.0	......	two 500,000	500,000	400,000
300.0	.....	580.0	290.0	232.0	......	two 600,000	600,000	500,000

* These motors are thrown directly on the line; all others are provided with auto-starters set to give a starting torque equal to full-load running torque.

† Values of current are for a two-phase, four-wire system; if three wires are used, current in common wire would be 1.41 times value given. Values for single-phase motors would be double the values given in the table.

‡ Sizes of wire are for squirrel-cage motors. For slip-ring motors, smaller sizes can be used. See paragraph 331.

TABLE 24. (Par. 168)

Power Factor of Induction Motors *

(Two and three-phase)

Horsepower.	Power Factor.	
	¾ Load.	Full Load.
2	0.71	0.79
5	0.82	0.85
10	0.79	0.84
20	0.83	0.88
50	0.85	0.89
100	0.87	0.91
200	0.94	0.96

* For 60 cycles; 25-cycle motors are practically the same.

TABLE 25. (Par. 189)

Usual Speed Ratings of Motors

Horsepower.	D.C.				A.C., 60 Cycles.				A.C., 25 Cycles.		
	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.
1	1750	1150	.....	.....	1675	1100					
1.5	1750	1150	.....	.....	1690	1120					
2	1750	1150	.....	.....	1720	1120	.....	.....	1445	710	
3	1750	1150	.....	.....	1730	1130	.....	.....	1445	720	
5	1750	1150	800	.....	1735	1140	850	.....	1445	720	
7.5	1750	1150	850	.....	1740	1140	855	.....	1450	725	
10	1750	1150	800	.....	1740	1150	860	.....	1455	725	
15	1750	1150	850	600	1740	1155	860	680	1455	730	480
20	1750	1150	800	600	1740	1160	860	685	1465	730	485
25	1750	1100	825	600	1755	1160	865	685	1465	730	485
30	1750	1150	850	675	1755	1160	865	685	1465	725	480
40	1700	1150	800	600	1755	1170	870	685	1460	725	480
50	1700	1150	750	570	1755	1170	870	690	1460	730	485

Note. Above are approximate full-load speeds.

TABLE 26. (Par. 208)

Standard Pulley Sizes for Motors *

Motor Sizes.								Pulley.	
H.P.	R.P.M.	H.P.	R.P.M.	H.P.	R.P.M.	H.P.	R.P.M.	Diam., Ins.	Face, Ins.
				1	1150	2	1750	4	3
				2	1150	3	1750	4	3
				3	1150	5	1750	5	4
				5	1150	7.5	1750	6	4
		5	800	7.5	1150	10	1750	7	5
		7.5	850	10	1150	15	1750	8	6
		10	800	15	1150	20	1750	9	7
		15	850	20	1150	30	1750	10	8
15	600	20	800	30	1150	40	1700	11	10
20	600	30	850	40	1150	50	1700	12	11
30	675	40	800	50	1150	....	....	13	12
40	600	50	750	75	1150	.....	....	14	12
50	570	75	850	100	1150	.....	....	16	13

* Recommended by "The Electric Power Club," an association of the principal motor manufacturers.

TABLE 27. (Par. 208)

Horsepower Transmitted per Inch of Width by Leather Belts with Pulleys of Equal Diameters *

Diam. of Pulley, Ins.	Revolutions per Minute.												
	100	200	300	400	500	600	800	1000	1200	1400	1600	1800	2000
	Single Belts.												
3	0.11	0.19	0.28	0.38	0.47	0.57	0.75	0.93	1.08	1.25	1.43	1.61	1.79
4	0.13	0.25	0.38	0.50	0.63	0.75	0.99	1.22	1.45	1.68	1.91	2.13	2.33
5	0.16	0.31	0.47	0.63	0.79	0.93	1.22	1.51	1.82	2.08	2.34	2.58	2.84
6	0.19	0.37	0.57	0.75	0.94	1.10	1.45	1.79	2.13	2.44	2.74	3.02	3.27
8	0.25	0.50	0.76	0.99	1.23	1.46	1.90	2.34	2.73	3.11	3.44	3.72	3.93
10	0.31	0.63	0.94	1.22	1.51	1.80	2.33	2.84	3.27	3.66	3.94	4.43	4.22
12	0.37	0.75	1.12	1.46	1.80	2.13	2.74	3.28	3.70	4.02	4.20	4.21	
14	0.43	0.87	1.29	1.69	2.08	2.45	3.11	3.65	4.03	4.21	4.17		
16	0.50	0.98	1.46	1.91	2.34	2.74	3.44	3.93	4.20	4.17			
18	0.56	1.10	1.63	2.13	2.60	3.02	3.72	4.13	4.21				
20	0.62	1.22	1.80	2.34	2.84	3.27	3.94	4.22					
24	0.74	1.45	2.14	2.74	3.28	3.70	4.20						
28	0.86	1.68	2.45	3.11	3.66	4.02	4.17						
32	0.98	1.92	2.75	3.44	3.95	4.20							
36	1.10	2.14	3.03	3.72	4.43	4.21							
40	1.22	2.35	3.28	3.93	4.22								
44	1.34	2.55	3.52	4.10	4.19								
48	1.45	2.74	3.73	4.20									
52	1.57	2.93	3.89	4.23									
56	1.68	3.11	4.02	4.17									
60	1.80	3.27	4.13										

* Adapted from National Electric Light Association, "Salesman's Handbook."

TABLE 27—*Continued*

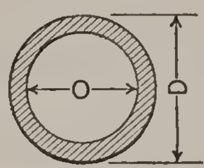
Diam. of Pulley, Ins.	Revolutions per Minute.												
	100	200	300	400	500	600	800	1000	1200	1400	1600	1800	2000
	Double Belts.												
3	0.16	0.29	0.44	0.59	0.74	0.90	1.20	1.48	1.78	2.07	2.36	2.63	2.91
4	0.19	0.39	0.59	0.79	0.98	1.20	1.58	1.97	2.35	2.73	3.09	3.45	3.78
5	0.24	0.49	0.74	0.99	1.23	1.49	1.97	2.45	2.91	3.36	3.78	4.20	4.60
6	0.29	0.59	0.88	1.19	1.48	1.78	2.36	2.90	3.45	3.95	4.44	4.90	5.33
8	0.39	0.79	1.19	1.58	1.97	2.36	3.08	3.78	4.45	5.06	5.60	6.06	6.45
10	0.49	0.99	1.49	1.98	2.45	2.92	3.80	4.61	5.34	5.95	6.46	6.75	6.85
12	0.59	1.19	1.78	2.37	2.90	3.45	4.45	5.33	6.08	6.60	6.83	6.81	
14	0.69	1.39	2.07	2.74	3.36	3.96	5.05	5.96	6.52	6.85	6.75		
16	0.79	1.58	2.35	3.10	3.79	4.45	5.59	6.45	6.83	6.75			
18	0.88	1.78	2.63	3.46	4.21	4.91	6.07	6.75	6.80				
20	0.98	1.97	2.91	3.80	4.61	5.34	6.47	6.86					
24	1.19	2.35	3.45	4.45	5.33	6.08	6.83						
28	1.39	2.72	3.95	5.06	5.96	6.63	6.74						
32	1.58	3.08	4.46	5.59	6.46	6.84							
36	1.78	3.45	4.90	6.07	6.75	6.81							
40	1.97	3.79	5.34	6.46	6.86								
44	2.16	4.13	5.73	6.71	6.78								
48	2.35	4.45	6.07	6.83									
52	2.54	4.76	6.38	6.85									
56	2.73	5.06	6.60	6.74									
60	2.91	5.29	6.75										

When pulleys are of unequal diameters and are approximately 15 ft. between centres, find the horse-power from the table, using the smaller size pulley diameter and speed and then multiply by the faetor found below:

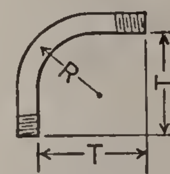
Ratio of pulleys..	8 to 1	7 to 1	6 to 1	5 to 1	4 to 1	3 to 1	2 to 1
Faetor..........	0.85	0.88	0.90	0.92	0.94	0.96	0.98

TABLE 28. (Par. 225)

Dimensions of Iron Conduit and Elbows.



Conduit



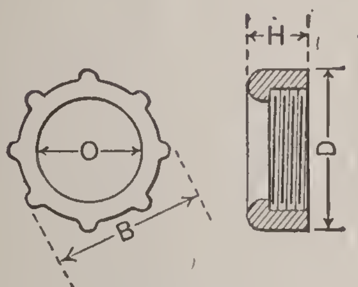
Elbow

Size.	D Outside Diam.		O Inside Diam.		Weight per Foot, Lbs.	R Radius.	T Offset.	Weight per 100 in Lbs.
	Decimal.	Nearest 64th.	Decimal.	Nearest 64th.				
$\frac{1}{4}$	0.540	$\frac{35}{64}$	0.364	$\frac{23}{64}$	0.425	$4\frac{1}{4}$	$7\frac{1}{2}$	42
$\frac{3}{8}$	0.675	$\frac{43}{64}$	0.493	$\frac{32}{64}$	0.568	$4\frac{1}{4}$	$7\frac{1}{2}$	53
$\frac{1}{2}$	0.840	$\frac{54}{64}$	0.622	$\frac{40}{64}$	0.852	$4\frac{1}{4}$	$7\frac{3}{8}$	75
$\frac{3}{4}$	1.050	$1\frac{3}{64}$	0.824	$\frac{53}{64}$	1.134	$5\frac{3}{8}$	$8\frac{3}{8}$	120
1	1.315	$1\frac{20}{64}$	1.049	$1\frac{3}{64}$	1.684	$5\frac{3}{4}$	$9\frac{1}{2}$	200
$1\frac{1}{4}$	1.660	$1\frac{42}{64}$	1.380	$1\frac{24}{64}$	2.281	$7\frac{1}{4}$	$10\frac{7}{8}$	300
$1\frac{1}{2}$	1.900	$1\frac{58}{64}$	1.610	$1\frac{39}{64}$	2.731	$8\frac{1}{4}$	$12\frac{5}{8}$	427
2	2.375	$2\frac{24}{64}$	2.067	$2\frac{4}{64}$	3.678	$9\frac{1}{2}$	$15\frac{1}{4}$	700
$2\frac{1}{2}$	2.875	$2\frac{56}{64}$	2.469	$2\frac{30}{64}$	5.819	$10\frac{1}{2}$	$17\frac{3}{8}$	1300
3	3.500	$3\frac{32}{64}$	3.068	$3\frac{4}{64}$	7.616	13	$19\frac{1}{2}$	1700
$3\frac{1}{2}$	4.000	4	3.548	$3\frac{35}{64}$	9.202	15	$21\frac{1}{4}$	2300
4	4.500	$4\frac{32}{64}$	4.026	$4\frac{2}{64}$	10.889	16	$22\frac{1}{2}$	2700
$4\frac{1}{2}$	5.000	5	4.506	$4\frac{32}{64}$	12.642	18	$24\frac{3}{8}$	3100
5	5.563	$5\frac{36}{64}$	5.047	$5\frac{3}{64}$	14.810	24	32	5500
6	6.625	$6\frac{40}{64}$	6.065	$6\frac{4}{64}$	19.185	30	$39\frac{3}{4}$	9000

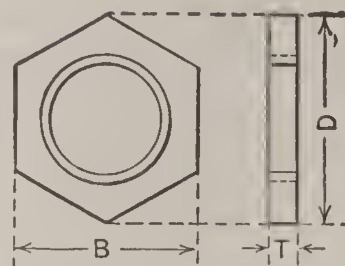
Conduit is furnished in 10-foot lengths, threaded on both ends, with one coupling.

TABLE 29 (Par. 228)

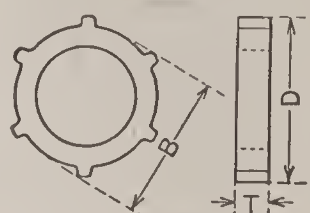
Dimensions of Locknuts and Bushings for Iron Conduit *



Bushings.



Style No. 1. Locknuts.



Style No. 2. Locknuts.

All dimensions in inches.

Size of Conduit.	*B*	*D*	*H*	*O*	Style.	*B*	*D*	*T*
$\frac{3}{8}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{11}{32}$	$\frac{1}{2}$	1	$\frac{29}{32}$	$1\frac{1}{32}$	$\frac{5}{32}$
$\frac{1}{2}$	$\frac{15}{16}$	1	$\frac{3}{8}$	$\frac{5}{8}$	1	1	$1\frac{5}{64}$	$\frac{5}{32}$
$\frac{3}{4}$	$1\frac{7}{32}$	$1\frac{5}{16}$	$\frac{7}{16}$	$\frac{13}{16}$	1	$1\frac{1}{4}$	$1\frac{11}{32}$	$\frac{5}{32}$
1	$1\frac{15}{32}$	$1\frac{9}{16}$	$\frac{17}{32}$	$1\frac{1}{16}$	1	$1\frac{9}{16}$	$1\frac{11}{16}$	$\frac{5}{32}$
$1\frac{1}{4}$	$1\frac{13}{16}$	$1\frac{15}{16}$	$\frac{19}{32}$	$1\frac{5}{16}$	2	$1\frac{29}{32}$	$2\frac{3}{32}$	$\frac{5}{16}$
$1\frac{1}{2}$	$2\frac{1}{32}$	$2\frac{5}{32}$	$\frac{5}{8}$	$1\frac{5}{8}$	2	$2\frac{1}{4}$	$2\frac{7}{16}$	$\frac{11}{32}$
2	$2\frac{9}{16}$	$2\frac{3}{4}$	$\frac{5}{8}$	2	2	$2\frac{23}{32}$	$2\frac{15}{16}$	$\frac{11}{32}$
$2\frac{1}{2}$	$3\frac{3}{32}$	$3\frac{11}{16}$	$\frac{25}{32}$	$2\frac{1}{2}$	2	$3\frac{7}{32}$	$3\frac{15}{32}$	$\frac{3}{8}$
3	$3\frac{11}{16}$	$3\frac{15}{16}$	$\frac{27}{32}$	3	2	$3\frac{29}{32}$	$4\frac{3}{16}$	$\frac{13}{32}$
$3\frac{1}{2}$	$4\frac{1}{4}$	$4\frac{1}{2}$	$\frac{7}{8}$	$3\frac{1}{2}$	2	$4\frac{9}{16}$	$4\frac{13}{16}$	$\frac{13}{32}$
4	$4\frac{7}{8}$	$5\frac{1}{8}$	$\frac{15}{16}$	4	2	$5\frac{1}{8}$	$5\frac{3}{8}$	$\frac{7}{16}$
5	$6\frac{1}{8}$	$6\frac{7}{16}$	$1\frac{1}{8}$	5	2	$6\frac{1}{2}$	$6\frac{13}{16}$	$\frac{9}{16}$

* "Star" bushings and locknuts, made by the Steel City Electric Co.

TABLE 30. (Par. 229)

SIZES OF IRON CONDUIT FOR RUBBER COVERED WIRES *

Size of Wire, B. & S.	Size of Conduit, Inches. Number of Wires in One Conduit.			
	1	2	3	4
14†	½	½	½	¾
12†	½	¾	¾	¾
10†	½	¾	¾	1
8	½	1	1	1
6	½	1	1¼	1¼
5	¾	1¼	1¼	1¼
4	¾	1¼	1¼	1½
3	¾	1¼	1¼	1½
2	¾	1¼	1½	1½
1	¾	1½	1½	2
0	1	1½	2	2
00	1	2	2	2½
000	1	2	2	2½
0,000	1¼	2	2½	2½
300,000	1¼	2½	2½	3
400,000	1¼	3	3	3½
500,000	1½	3	3	3½
600,000	1½	3	3½	
700,000	2	3½	3½	
800,000	2	3½	4	
900,000	2	3½	4	
1,000,000	2	4	4	
1,250,000	2½	4½	4½	
1,500,000	2½	4½	5	
1,750,000	3	5	5	
2,000,000	3	5	6	
14 duplex †	½	¾	1	1
12 duplex †	½	¾	1	1¼
10 duplex †	¾	1	1¼	1¼

* Adopted by the National Electric Contractors' Association and specified by the National Electric Code. (Rule 28.)

† These sizes are solid, all others are stranded.

NOTE. Sizes are based on three elbows up to No. 10 and two for larger wires. For more elbows or long runs, the next larger size of conduit should be used when the maximum size of wire specified for a conduit is used. For example, three No. 1 wires should be installed in a 2-in. conduit for long runs.

TABLE 31. (Par. 229)

Sizes of Pull Boxes

Size of Conduit, Ins.	Length in Ins. for Number of Wires Given Below.				
	1 Wire.	2 Wires.	3 Wires.	4 Wires.	Small Wires.
1	18	12	12	12	12
1¼	24	18	18	12	12
1½	30	18	18	18	12
2	36	24	24	18	12
2½	36	24	24	24	12
3	48	30	30	24	18
3½	......	36	30	30	18
4	......	36	36	......	18
5	......	48	36	......	18
6	......	......	48	......	18

Where several wires are in the same conduit, the length can be made less, since each wire is of a smaller diameter and therefore can be more easily bent.

See Fig. 133 for illustration of pull box.

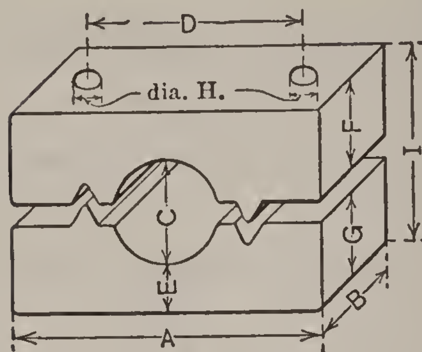
TABLE 32. (Par. 230)

Spacing of Anchors on Vertical Runs *

Size.	Distance between Anchors. Feet.
Nos. 14 to 0	100
00 to 0000	80
0000 to 350,000 cir. mils	60
350,000 to 500,000 cir. mils	50
500,000 to 750,000 cir. mils	40
over 750,000 cir. mils	35

* National Electrical Code.

TABLE 33. (Par. 247)



DIMENSIONS OF B. & D. CLEATS *

No.	Sizes of Wires.	Dimensions in Inches.				
		A	B	C	D	E
1	14–6	2	$\frac{13}{16}$	$\frac{3}{16}$–$\frac{3}{8}$	$1\frac{1}{4}$	1
$1\frac{1}{2}$	10–2	$2\frac{1}{4}$	$\frac{15}{16}$	$\frac{1}{4}$–$\frac{1}{2}$	$1\frac{5}{16}$	1
2	2–0	$2\frac{1}{4}$	$1\frac{1}{16}$	$\frac{3}{8}$–$\frac{5}{8}$	$1\frac{3}{8}$	1
$2\frac{1}{2}$	0–000	$2\frac{3}{4}$	$1\frac{3}{16}$	$\frac{9}{16}$–$\frac{3}{4}$	$1\frac{11}{16}$	1
3	000–200,000 c.m.	$3\frac{3}{16}$	$1\frac{5}{16}$	$\frac{9}{16}$–$\frac{13}{16}$	2	1
$3\frac{1}{2}$	200,000–500,000 c.m.	$3\frac{1}{4}$	$1\frac{5}{16}$	$\frac{11}{16}$–$1\frac{1}{8}$	2	1
4	500,000–1,000,000 c.m.	$3\frac{3}{4}$	$1\frac{3}{8}$	1 –$1\frac{3}{8}$	$2\frac{3}{8}$	1
$4\frac{1}{2}$	1,000,000–2,000,000 c.m.	$5\frac{3}{8}$	2	$1\frac{7}{16}$–2	$3\frac{9}{16}$	$1\frac{3}{16}$

No.	Sizes of Wires.	Dimensions in Inches.					Size of Screw or Bolt.
		F	G	H Diam.	I		
					Max.	Min.	
1	14–6	$\frac{5}{8}$	$1\frac{1}{8}$	$\frac{1}{4}$	$1\frac{15}{16}$	$1\frac{3}{4}$	No. 12
$1\frac{1}{2}$	10–2	$\frac{3}{4}$	$1\frac{3}{16}$	$\frac{5}{16}$	$2\frac{3}{16}$	$1\frac{15}{16}$	No. 14†
2	2–0	$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{5}{16}$	$2\frac{1}{4}$	2	No. 14†
$2\frac{1}{2}$	0–000	$\frac{15}{16}$	$1\frac{5}{16}$	$\frac{5}{16}$	$2\frac{7}{16}$	$2\frac{1}{4}$	$\frac{1}{4}$″
3	000–200,000 c.m.	1	$1\frac{1}{4}$	$\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{1}{4}$	$\frac{5}{16}$″
$3\frac{1}{2}$	200,000–500,000 c.m.	$1\frac{5}{16}$	$1\frac{5}{16}$	$\frac{13}{32}$	3	$2\frac{5}{8}$	$\frac{3}{8}$″
4	500,000–1,000,000 c.m.	$1\frac{5}{8}$	$1\frac{5}{8}$	$\frac{13}{32}$	$3\frac{5}{8}$	$3\frac{1}{4}$	$\frac{3}{8}$″
$4\frac{1}{2}$	1,000,000–2,000,000 c.m.	2	2	$\frac{9}{16}$	$4\frac{1}{2}$	4	$\frac{1}{2}$″

* Dimensions taken from samples.

† Or $\frac{1}{4}$-inch lag screw or machine bolt.

Round head blued-wood screws or round-head machine screws with nuts are generally used for sizes 1 to 2 inclusive.

TABLE 34. (Par. 256)

Dimensions of Bare Stranded Copper Cables *

Concentric Stranding

Size.	Diam. of Cable. Inches	Number of Wires in Cable.						Resis., Ohms per 1000 Ft., 25° C. (77° Fahr.)
		127	91	61	37	19	7	
		Diameter of Wires, Mils.						
2,000,000 c.m.	**1.631**	**125.5**	148.2	....	....	....	...	0.00539
1,900,000 "	**1.590**	**122.3**	144.5	....	....	....	...	0.00568
1,800,000 "	**1.548**	**119.1**	140.7	....	....	....	...	0.00599
1,700,000 "	**1.504**	**115.7**	136.7	....	....	....	...	0.00634
1,600,000 "	**1.459**	**112.2**	132.6	162.0	....	....	...	0.00674
1,500,000 "	**1.412**	108.7	**128.4**	156.8	....	....	...	0.00719
1,400,000 "	**1.364**	150.1	**124.0**	151.5	....	....	...	0.00770
1,300,000 "	**1.315**	101.2	**119.5**	146.0	....	....	...	0.00830
1,200,000 "	**1.263**	97.2	**114.8**	140.3	....	....	...	0.00899
1,100,000 "	**1.209**	93.1	**109.9**	134.3	....	....	...	0.00981
1,000,000 "	**1.152**	....	104.8	**128.0**	164.4	....	...	0.01080
950,000 "	**1.123**	....	102.2	**124.8**	160.3	....	...	0.0114
900,000 "	**1.093**	....	99.5	**121.5**	156.0	....	...	0.0120
850,000 "	**1.062**	....	96.7	**118.0**	151.6	....	...	0.0127
800,000 "	**1.031**	....	93.8	**114.5**	147.1	....	...	0.0135
750,000 "	**0.998**	....	....	**110.9**	142.4	....	...	0.0144
700,000 "	**0.964**	....	....	**107.1**	137.5	....	...	0.0154
650,000 "	**0.929**	....	....	**103.2**	132.6	....	...	0.0166
600,000 "	**0.893**	....	....	**99.2**	127.4	....	...	0.0180
550,000 "	**0.855**	....	....	**95.0**	121.9	170.1	...	0.0196
500,000 "	**0.814**	....	....	90.5	**116.2**	162.2	...	0.0216
450,000 "	**0.772**	....	....	85.9	**110.3**	153.9	...	0.0240
400,000 "	**0.728**	....	....	81.0	**104.0**	145.1	...	0.0270
350,000 "	**0.681**	....	....	75.8	**97.3**	135.8	...	0.0308
300,000 "	**0.630**	....	....	....	**90.0**	125.7	...	0.0360
250,000 "	**0.575**	....	....	....	**82.2**	114.7	...	0.0431
0,000 B.& S	**0.528**	....	....	....	75.6	**105.5**	...	0.0509
000 "	**0.470**	....	....	....	67.3	**94.0**	...	0.0642
00 "	**0.418**	....	....	....	60.0	**83.7**	...	0.0811
0 "	**0.373**	....	....	....	53.4	**74.5**	128.8	0.102
1 "	**0.332**	....	....	....	....	**66.4**	109.3	0.129
2 "	**0.292**	....	....	....	....	59.1	**97.4**	0.162
3 "	**0.260**	....	....	....	....	52.6	**86.7**	0.205
4 "	**0.232**	....	....	....	....	46.9	**77.2**	0.259
5 "	**0.206**	....	....	....	....	41.7	**68.8**	0.326
6 "	**0.184**	....	....	....	....	....	**61.2**	0.410
7 "	**0.164**	....	....	....	....	....	**54.5**	0.519
8 "	**0.146**	....	....	....	....	....	**48.6**	0.654

* From the Bureau of Standards, Circular No. 31.

Note. Figures in black-face type apply to standard stranding.

TABLE 35. (Par. 257.)

Dimensions of Insulated Wires *

With N. E. Code thickness of insulation for 0–600 volts.

Size.	Rubber Insulation.					Slow-burning Insulation. Diam., Ins.
	Thickness of Insulation, Ins.	Outside Diameter.				
		Single Braid.		Double Braid.		
		Mils.	Ins.	Mils.	Ins.	
†18 B. & S.	$\frac{1}{64}$ ‡	112	$\frac{7}{64}$	154	$\frac{5}{32}$	
†16 "	$\frac{1}{32}$ ‡	155	$\frac{5}{32}$	197	$\frac{13}{64}$	
†14 "	$\frac{3}{64}$	208	$\frac{13}{64}$	258	$\frac{1}{4}$	$\frac{3}{16}$
†12 "	$\frac{3}{64}$	225	$\frac{7}{32}$	275	$\frac{9}{32}$	$\frac{7}{32}$
†10 "	$\frac{3}{64}$	246	$\frac{1}{4}$	296	$\frac{19}{64}$	$\frac{1}{4}$
8 "	$\frac{3}{64}$	290	$\frac{19}{64}$	340	$\frac{11}{32}$	$\frac{9}{32}$
6 "	$\frac{1}{16}$	360	$\frac{23}{64}$	410	$\frac{13}{32}$	$\frac{11}{32}$
5 "	$\frac{1}{16}$	396	$\frac{25}{64}$	460	$\frac{15}{32}$	$\frac{3}{8}$
4 "	$\frac{1}{16}$	422	$\frac{27}{64}$	486	$\frac{31}{64}$	$\frac{27}{64}$
3 "	$\frac{1}{16}$	451	$\frac{29}{64}$	515	$\frac{33}{64}$	$\frac{29}{64}$
2 "	$\frac{1}{16}$	504	$\frac{1}{2}$	588	$\frac{19}{32}$	$\frac{31}{64}$
1 "	$\frac{5}{64}$	571	$\frac{37}{64}$	655	$\frac{21}{32}$	$\frac{33}{64}$
0 "	$\frac{5}{64}$	613	$\frac{39}{64}$	697	$\frac{45}{64}$	$\frac{37}{64}$
00 "	$\frac{5}{64}$	659	$\frac{21}{32}$	743	$\frac{3}{4}$	$\frac{41}{64}$
000 "	$\frac{5}{64}$	709	$\frac{45}{64}$	793	$\frac{51}{64}$	$\frac{49}{64}$
0,000 "	$\frac{5}{64}$	767	$\frac{49}{64}$	851	$\frac{55}{64}$	$\frac{53}{64}$
250,000 c.m.	$\frac{3}{32}$	845	$\frac{27}{32}$	929	$\frac{15}{16}$	$\frac{7}{8}$
300,000 "	$\frac{3}{32}$	902	$\frac{29}{32}$	986	$\frac{63}{64}$	$\frac{15}{16}$
350,000 "	$\frac{3}{32}$	952	$\frac{61}{64}$	1036	$1\frac{1}{32}$	$\frac{31}{32}$
400,000 "	$\frac{3}{32}$	1001	1	1085	$1\frac{3}{32}$	$1\frac{3}{32}$
450,000 "	$\frac{3}{32}$	1044	$1\frac{3}{64}$	1128	$1\frac{1}{8}$	$1\frac{9}{64}$
500,000 "	$\frac{3}{32}$	1087	$1\frac{3}{32}$	1171	$1\frac{11}{64}$	$1\frac{13}{64}$
550,000 "	$\frac{7}{64}$	1157	$1\frac{5}{32}$	1241	$1\frac{1}{4}$	
600,000 "	$\frac{7}{64}$	1194	$1\frac{3}{16}$	1278	$1\frac{9}{32}$	$1\frac{9}{32}$
650,000 "	$\frac{7}{64}$	1231	$1\frac{15}{64}$	1315	$1\frac{5}{16}$	
700,000 "	$\frac{7}{64}$	1266	$1\frac{17}{64}$	1350	$1\frac{23}{64}$	$1\frac{27}{32}$
750,000 "	$\frac{7}{64}$	1300	$1\frac{19}{64}$	1384	$1\frac{25}{64}$	
800,000 "	$\frac{7}{64}$	1333	$1\frac{21}{64}$	1417	$1\frac{27}{64}$	$1\frac{33}{64}$
850,000 "	$\frac{7}{64}$	1365	$1\frac{23}{64}$	1449	$1\frac{29}{64}$	
900,000 "	$\frac{7}{64}$	1395	$1\frac{25}{64}$	1479	$1\frac{31}{64}$	$1\frac{9}{16}$
950,000 "	$\frac{7}{64}$	1425	$1\frac{27}{64}$	1509	$1\frac{33}{64}$	
1,000,000 "	$\frac{7}{64}$	1455	$1\frac{29}{64}$	1539	$1\frac{17}{32}$	$1\frac{39}{64}$
1,250,000 "	$\frac{1}{8}$	1623	$1\frac{5}{8}$	1707	$1\frac{45}{64}$	$1\frac{11}{16}$
1,500,000 "	$\frac{1}{8}$	1747	$1\frac{3}{4}$	1831	$1\frac{53}{64}$	$1\frac{3}{4}$
1,750,000 "	$\frac{1}{8}$	1860	$1\frac{55}{64}$	1944	$1\frac{61}{64}$	$1\frac{7}{8}$
2,000,000 "	$\frac{1}{8}$	1965	$1\frac{31}{32}$	2049	$2\frac{3}{64}$	2

* Standard Underground Cable Co.

† These sizes are solid. All others are stranded.

‡ Fixture wire.

TABLE 36. (Par. 261)

CURRENT-CARRYING CAPACITY OF WIRES

0–600 volt insulation, N. E. C. Standard for interior wiring

Size, Circ. Mils.	Size, B. & S. Gauge.	Rubber Insulation, Amperes. A.	Other Insulations, Amperes. B.
1,620	18*	3	5
2,580	16*	6	10
4,110	14	15	20
6,530	12	20	25
10,400	10	25	30
16,500	8	35	50
26,300	6	50	70
33,100	5	55	80
41,700	4	70	90
52,600	3	80	100
66,400	2	90	125
83,700	1	100	150
106,000	0	125	200
133,000	00	150	225
168,000	000	175	275
212,000	0000	225	325
300,000	....	275	400
400,000	....	325	500
500,000	....	400	600
600,000	....	450	680
700,000	....	500	760
800,000	....	550	840
900,000	....	600	920
1,000,000	....	650	1000
1,100,000	....	690	1080
1,200,000	....	730	1150
1,300,000	....	770	1220
1,400,000	....	810	1290
1,500,000	....	850	1360
1,600,000	....	890	1430
1,700,000	....	930	1490
1,800,000	....	970	1550
1,900,000	....	1010	1610
2,000,000	....	1050	1670

NOTE.—Voltage drop is not considered in the above table.

* Wires smaller than No. 14 B. & S. gauge should not be used except for fixture wiring and pendant cords.

TABLE 37. (Par. 295)

Dimensions of Lighting Panel Board Cabinets *

		125 Volt.†								250 Volt.†			
		Style A.		Style B.		Style C.		Style D.		Style A.		Style C.	
	Circuits.	Height.	Width.	Height.	Width.	Height.	Width.	Height.	Width.	Height.	Width.	Height.	Width.
Double Branch.	2	15.5	23	15.5	23	15.5	19	15.5	19	17.5	25	17.5	19
	4	19.5	23	19.5	23	19.5	19	19.5	19	19.5	25	19.5	19
	6	21.5	23	21.5	23	21.5	19	21.5	19	23.5	25	23.5	19
	8	23.5	23	25.5	23	23.5	19	25.5	19	27.5	25	27.5	19
	10	25.5	23	27.5	23	25.5	19	27.5	19	29.5	25	29.5	19
	12	29.5	23	31.5	23	29.5	19	31.5	19	33.5	25	33.5	19
	14	31.5	23	35.5	23	31.5	19	35.5	19	35.5	25	35.5	19
	16	35.5	23	37.5	23	35.5	19	37.5	19	39.5	25	39.5	19
	18	37.5	23	41.5	23	37.5	19	41.5	19	43.5	25	43.5	19
	20	39.5	23	43.5	23	39.5	19	43.5	19	45.5	25	45.5	19
	22	41.5	23	47.5	23	41.5	19	47.5	19	49.5	25	49.5	19
	24	45.5	23	49.5	23	45.5	19	49.5	19	53.5	25	53.5	19
	26	47.5	23	53.5	23	47.5	19	53.5	19	57.5	25	57.5	19
	28	49.5	23	55.5	23	49.5	19	55.5	19	59.5	25	59.5	19
	30	51.5	23	59.5	23	51.5	19	59.5	19	63.5	25	63.5	19
	32	55.5	23	61.5	23	55.5	19	61.5	19	67.5	25	67.5	19
Single Branch.	2	19.5	18	19.5	18	19.5	16.5	19.5	16.5	19.5	19	19.5	16.5
	3	21.5	18	21.5	18	21.5	16.5	21.5	16.5	23.5	19	23.5	16.5
	4	23.5	18	25.5	18	23.5	16.5	25.5	16.5	27.5	19	27.5	16.5
	5	25.5	18	27.5	18	25.5	16.5	27.5	16.5	29.5	19	29.5	16.5
	6	29.5	18	31.5	18	29.5	16.5	31.5	16.5	33.5	19	33.5	16.5
	7	31.5	18	33.5	18	31.5	16.5	33.5	16.5	35.5	19	35.5	16.5
	8	33.5	18	37.5	18	33.5	16.5	37.5	16.5	39.5	19	39.5	16.5
	9	35.5	18	39.5	18	35.5	16.5	39.5	16.5	43.5	19	43.5	16.5
	10	39.5	18	43.5	18	39.5	16.5	43.5	16.5	45.5	19	45.5	16.5
	11	41.5	19	47.5	19	41.5	16.5	45.5	16.5	49.5	19	49.5	16.5
	12	45.5	19	49.5	19	45.5	16.5	49.5	16.5	53.5	19	53.5	16.5
	13	47.5	19	53.5	19	47.5	16.5	53.5	16.5	55.5	19	55.5	16.5

"Double branch" have circuits both sides of bus bars; "single branch" on one side.

Style A—Enclosed fuses and knife switches on branches, no main fuses or switch.

Style B—Plug fuses and knife switches on branches, no main fuses or switch.

Style C—Enclosed fuses, no switches on branches, no main fuses or switch.

Style D—Plug fuses, no switches on branches, no main fuses or switch.

All boxes are $4\frac{3}{8}$ inches deep outside, not including trim.

Dimensions given above are for steel boxes with a gutter 3 inches wide on top, bottom and sides and with a slate lining.

* Crouse-Hinds Co.

† Above sizes apply to panels with two-wire mains. Panels with three-wire mains are same height and about 2 inches wider.

TABLE 38. (Par. 313)

Demand Factors for Motor Loads *

No. of Motors.	Character of Load.	Demand Factor.
1	Individual drives—tools, etc.	1.25
2	Individual drives—tools, etc.	1.00
3	Individual drives—tools, etc.	0.75 to 0.85
5	Individual drives—tools, etc.	0.60 to 0.70
10	Individual drives—tools, etc.	0.40 to 0.50
20	Individual drives—tools, etc.	0.40
1	Group drives	1.25
2 or more	Group drives	0.70 to 0.75
1	Fans, compressors, pumps, etc.	1.25
2 or more	Fans, compressors, pumps, etc.	0.85 to 1.00

The above values make no allowance for future increase in the load.
* Ratio of maximum load to connected load.

TABLE 39. (Par. 315)

Sizes of Fuses for Motors *

Horse-power.	D.C.			Two-phase A.C.†				Three-phase A.C.†			
	115 V.	230 V.	550 V.	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.
½	8	4	3	5	3	3	3	6	3	3	3
1	12	6	3	9	5	3	3	10	5	3	3
2	20	12	5	15	8	4	3	20	9	5	4
3	35	20	7	25	12	6	5	25	15	7	5
5	55	30	12	35	20	9	7	45	25	12	9
7½	80	40	20	60	30	15	12	60	35	15	12
10	100	50	25	70	35	20	15	85	45	20	20
15	150	80	35	100	50	25	20	125	65	30	25
20	200	100	45	150	70	40	30	175	80	40	35
25	250	125	50	175	85	45	35	200	100	50	40
30	300	150	65								
35	325	175	70	.....	120	60	50	.....	125	65	55
40	400	200	80								
50	450	225	100	.....	175	80	65	.....	200	100	75

* These values are for motors for constant speed or adjustable speed service. For varying speed service (cranes, etc.), see par. 315.

† These values are for slip-ring motors and for the "running fuses" for squirrel-cage motors. The "starting fuses" should be based on carrying capacity of wire. (See par. 331.) Where small motors are thrown directly upon the line, "starting fuses" only are used unless a two-throw switch is provided which cuts out the "running fuses" when starting.

TABLE 40. (Par. 317)

Values of Maximum Voltage Drop Allowable

	Per Cent.	Voltage Drop between Wires for 120 Volts.	Voltage Drop between Wires for 240 Volts.
Lighting circuits:			
Branches	1.5	1.8	3.6
Mains	1.0	1.2	2.4
Feeders	2.5	3.0	6.0
Total	5.0	6.0	12.0

	Per Cent.	Voltage Drop between Wires for 110 V.	220 V.	440 V.	550 V.
Power circuits:					
Branches	2.0	2.2	4.4	8.8	11.0
Mains	2.0	2.2	4.4	8.8	11.0
Feeders	6.0	6.6	13.2	26.4	33.0
Total	10.0	11.0	22.0	44.0	55.0

Above values are for the drop to the farthest lamp or motor.

TABLE 41. (Par. 319)

Branch Lighting Circuits

Maximum length of circuit for 1.5 per cent drop.

Size, B. & S. Gauge.	Distances in Feet.* 120 Volts. 12 Amp.	10 Amp.	6 Amp.	5 Amp.	240 Volts. 6 Amp.	5 Amp.	3 Amp.	2.5 Amp.
14	29	35	58	70	116	138	232	276
12	46	55	92	110	184	220	366	440
10	73	87	146	174	292	348		
8	116	139	232	278	464			

* Note that the distance given is in each case to the load centre and not to the end of the run.

TABLE 42. (Par. 323)

Skin Effect for Round Copper Conductors

Product of Cir. Mils and Cycles per Second.	Factor.
10,000,000	1.00
20,000,000	1.01
30,000,000	1.02
40,000,000	1.04
50,000,000	1.06
60,000,000	1.09
70,000,000	1.12
80,000,000	1.15
90,000,000	1.18
100,000,000	1.22
125,000,000	1.31
150,000,000	1.41
175,000,000	1.50
200,000,000	1.59

To find the skin effect, multiply the frequency by the size in circular mils. Find the corresponding factor from the table and multiply the direct-current resistance (given in Table 34) by this factor. The product will be the alternating current resistance. Thus for a 1,000,000 c.m. cable at 60 cycles, the factor is 1.09. Hence the resistance per 1000 ft., is $1.09 \times 0.0108 = 0.0118$ ohm. The table is correct for either stranded or solid wires.

TABLE 43. (Par 324)

Power Factors of Apparatus

	Power Factor.
Incandescent lamps and heaters	1.0
Arc lamps (multiple)	0.60
Cooper Hewitt lamps	0.85
Induction motors—up to 15 hp. (running)	0.80
Induction motors—above 15 hp. (running)	0.85
Induction motors—starting	0.50

Note. The values given for induction motors take into account the fact that as a rule the motors would not be carrying full load. The values refer to the sizes of individual motors. That is, if a feeder carries one 15-hp. and four 10-hp. motors, the total connected load is 55 hp., but the power factor should be taken as 0.80.

TABLE 44. (Par. 330)

Reactive and Resistance Factors

Power Factor.	Reactive Factor.	Resistance Factor.	Power Factor.	Reactive Factor.	Resistance Factor.
1.00	0	1.00	0.84	0.54	0.84
0.99	0.14	0.99	0.82	0.57	0.82
0.98	0.20	0.98	0.80	0.60	0.80
0.97	0.24	0.97	0.75	0.66	0.75
0.96	0.28	0.96	0.70	0.71	0.70
0.95	0.31	0.95	0.65	0.76	0.65
0.94	0.34	0.94	0.60	0.80	0.60
0.93	0.37	0.93	0.55	0.84	0.55
0.92	0.39	0.92	0.50	0.87	0.50
0.91	0.41	0.91	0.45	0.89	0.45
0.90	0.44	0.90	0.40	0.92	0.40
0.88	0.48	0.88	0.35	0.94	0.35
0.86	0.51	0.86	0.30	0.95	0.30
0.85	0.53	0.85			

TABLE 45. (Par. 334)

RATIO OF REACTANCE TO RESISTANCE

Size of Wire	Ratios for Distance between Wires of						
	In Conduit.	2½ Ins.	4 Ins.	5 Ins.	6 Ins.	8 Ins.	12 Ins.
				60 Cycles			
10	0.05	0.09	0.10	0.11	0.11	0.12	0.13
8	0.08	0.13	0.15	0.16	0.17	0.18	0.19
6	0.12	0.21	0.23	0.24	0.26	0.27	0.29
5	0.14	0.25	0.28	0.30	0.31	0.33	0.36
4	0.15	0.30	0.34	0.36	0.38	0.41	0.44
3	0.22	0.37	0.42	0.45	0.47	0.50	0.54
2	0.26	0.45	0.52	0.55	0.57	0.62	0.67
1	0.32	0.54	0.62	0.67	0.70	0.75	0.82
0	0.38	0.66	0.77	0.82	0.86	0.92	1.01
00	0.54	0.80	0.93	0.99	1.04	1.13	1.25
000	0.64	0.97	1.14	1.21	1.28	1.38	1.53
0000	0.76	1.17	1.38	1.48	1.56	1.70	1.87
300,000	1.01	1.54	1.84	1.98	2.10	2.28	2.52
400,000	1.49	1.93	2.33	2.52	2.67	2.92	3.26
500,000	1.75	2.30	2.80	3.03	3.22	3.54	
600,000	1.85	2.52	3.10	3.40	3.63		
700,000	2.06	2.84	3.54				
800,000	2.49	3.12					
900,000	2.69	3.39					
1,000,000	2.89	3.66					

TABLE 45—*Continued*

Size of Wires.	Ratios for Distance between Wires of						
	In Conduit.	2½ Ins.	4 Ins.	5 Ins.	6 Ins.	8 Ins.	12 Ins.
			40 Cycles				
10	0.03	0.06	0.07	0.07	0.07	0.08	0.09
8	0.05	0.09	0.10	0.11	0.11	0.12	0.13
6	0.08	0.14	0.15	0.16	0.17	0.18	0.19
5	0.09	0.17	0.19	0.20	0.21	0.22	0.24
4	0.10	0.20	0.23	0.24	0.25	0.27	0.29
3	0.15	0.25	0.28	0.30	0.31	0.33	0.36
2	0.17	0.30	0.35	0.37	0.38	0.41	0.45
1	0.21	0.36	0.41	0.45	0.47	0.50	0.55
0	0.25	0.44	0.51	0.55	0.57	0.61	0.67
00	0.36	0.53	0.62	0.66	0.69	0.75	0.83
000	0.43	0.65	0.76	0.81	0.85	0.92	1.02
0,000	0.51	0.78	0.92	0.99	1.04	1.13	1.25
300,000	0.67	1.02	1.22	1.32	1.40	1.52	1.67
400,000	1.00	1.28	1.55	1.68	1.77	1.95	2.17
500,000	1.17	1.53	1.87	2.02	2.14	2.36	2.63
600,000	1.23	1.68	2.07	2.27	2.42	2.67	3.02
700,000	1.38	1.90	2.36	2.58	2.76	3.05	3.45
800,000	1.67	2.08	2.63	2.87	3.08	3.40	
900,000	1.80	2.26	2.87	3.15	3.38		
1,000,000	1.93	2.45	3.08	3.40	3.67		

TABLE 45—*Continued*

Size of Wire.	Ratios for Distance between Wires of						
	In Conduit.	2½ Ins.	4 Ins.	5 Ins.	6 Ins.	8 Ins.	12 Ins.
	25 Cycles						
10	0.02	0.04	0.04	0.05	0.05	0.05	0.05
8	0.03	0.05	0.06	0.07	0.07	0.08	0.08
6	0.05	0.09	0.10	0.10	0.11	0.11	0.12
5	0.06	0.10	0.12	0.13	0.13	0.14	0.15
4	0.06	0.12	0.14	0.15	0.16	0.17	0.18
3	0.09	0.15	0.18	0.19	0.20	0.21	0.23
2	0.11	0.19	0.22	0.23	0.24	0.26	0.28
1	0.13	0.23	0.26	0.28	0.29	0.31	0.34
0	0.16	0.28	0.32	0.34	0.36	0.38	0.42
00	0.23	0.33	0.39	0.41	0.43	0.47	0.52
000	0.27	0.40	0.48	0.51	0.53	0.58	0.64
0,000	0.32	0.49	0.58	0.62	0.65	0.71	0.78
300,000	0.42	0.64	0.77	0.83	0.88	0.95	1.05
400,000	0.62	0.81	0.97	1.05	1.11	1.24	1.36
500,000	0.73	0.96	1.17	1.26	1.34	1.48	1.65
600,000	0.77	1.05	1.29	1.42	1.51	1.67	1.88
700,000	0.86	1.18	1.47	1.61	1.72	1.91	2.15
800,000	1.03	1.30	1.64	1.79	1.92	2.12	2.31
900,000	1.12	1.42	1.79	1.96	2.11	2.34	2.49
1,000,000	1.20	1.53	1.92	2.12	2.29	2.54	

TABLE 46. (Par. 334)

DROP FACTORS *

Ratio of Reactance to Resistance.	Drop Factors for Power Factors of							
	1.00	0.95	0.90	0.85	0.80	0.70	0.60	0.40
0.1	1.00	1.00	1.00	0.94	0.88	0.80	0.70	0.60
0.2	1.00	1.01	1.01	0.98	0.92	0.86	0.82	0.67
0.3	1.00	1.05	1.05	1.02	0.99	0.93	0.89	0.74
0.4	1.00	1.08	1.10	1.08	1.04	1.00	0.93	0.82
0.5	1.00	1.11	1.14	1.13	1.10	1.07	1.01	0.92
0.6	1.01	1.15	1.18	1.19	1.15	1.14	1.09	1.01
0.7	1.02	1.18	1.23	1.24	1.21	1.20	1.17	1.11
0.8	1.02	1.21	1.28	1.29	1.28	1.27	1.24	1.20
0.9	1.03	1.25	1.33	1.34	1.34	1.35	1.32	1.29
1.0	1.04	1.28	1.37	1.39	1.40	1.41	1.39	1.38
1.1	1.05	1.32	1.41	1.44	1.45	1.48	1.47	1.46
1.2	1.06	1.35	1.46	1.50	1.51	1.55	1.54	1.55
1.3	1.07	1.39	1.51	1.55	1.57	1.62	1.63	1.64
1.4	1.08	1.43	1.55	1.61	1.64	1.70	1.71	1.72
1.5	1.10	1.47	1.60	1.67	1.70	1.77	1.80	1.81
1.6	1.10	1.51	1.65	1.74	1.77	1.85	1.87	1.90
1.7	1.13	1.55	1.70	1.79	1.84	1.92	1.95	1.99
1.8	1.15	1.59	1.76	1.85	1.91	1.99	2.04	2.08
1.9	1.17	1.63	1.82	1.91	1.98	2.06	2.11	2.16
2.0	1.18	1.68	1.87	1.96	2.04	2.14	2.19	2.25
2.1	1.20	1.72	1.92	2.03	2.10	2.21	2.28	2.35
2.2	1.22	1.77	1.98	2.09	2.17	2.29	2.37	2.45
2.3	1.23	1.82	2.03	2.15	2.23	2.37	2.45	2.53
2.4	1.25	1.87	2.09	2.22	2.30	2.44	2.53	2.62

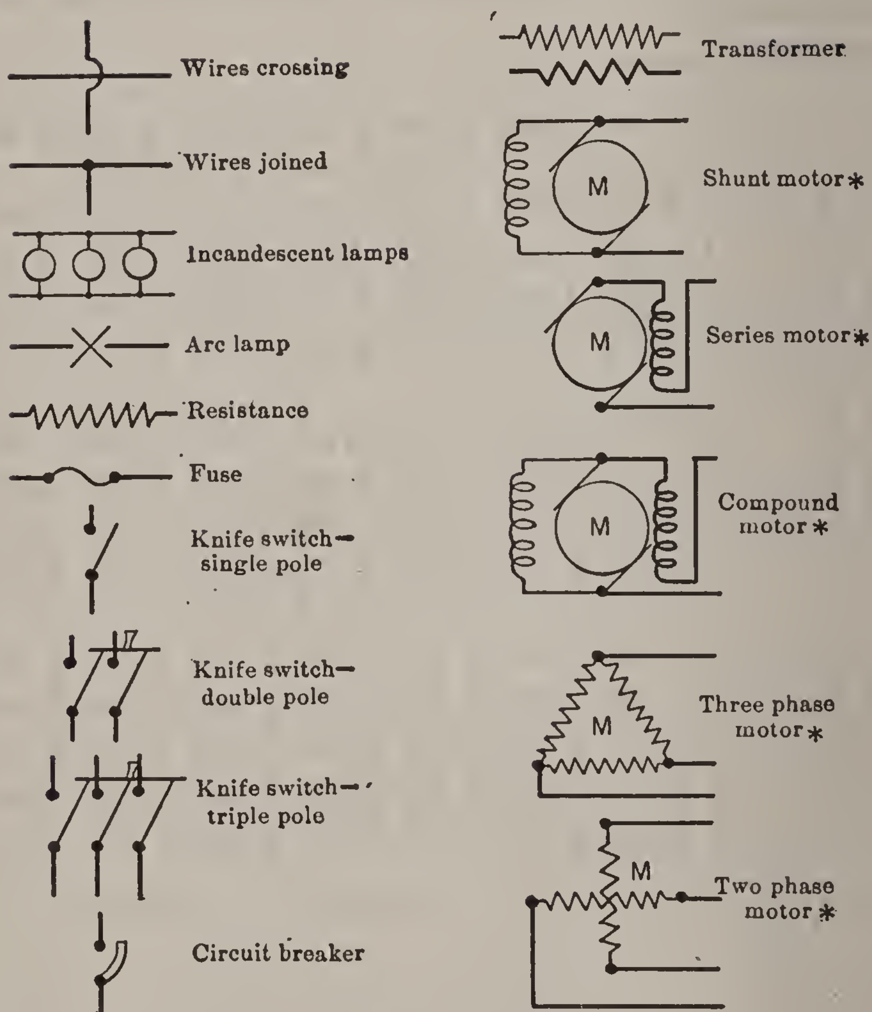
* Electric Journal, Vol. IV, p. 229.

TABLE 46—*Continued.*

Ratio of Reactance to Resistance	Drop Factors for Power Factors of							
	1.00	0.95	0.90	0.85	0.80	0.70	0.60	0.40
2.5	1.27	1.91	2.14	2.28	2.37	2.52	2.60	2.71
2.6	1.30	1.95	2.20	2.34	2.44	2.60	2.67	2.80
2.7	1.32	1.99	2.26	2.41	2.51	2.68	2.74	2.98
2.8	1.35	2.05	2.32	2.47	2.57	2.76	2.82	3.07
2.9	1.37	2.10	2.39	2.54	2.64	2.83	2.91	3.15
3.0	1.40	2.15	2.45	2.60	2.72	2.90	3.00	3.23
3.1	1.42	2.20	2.51	2.66	2.80	2.97	3.10	3.31
3.2	1.45	2.26	2.57	2.73	2.87	3.05	3.20	3.39
3.3	1.48	2.31	2.63	2.80	2.93	3.12	3.30	3.47
3.4	1.51	2.36	2.69	2.87	3.00	3.20	3.39	3.56
3.5	1.53	2.42	2.74	2.94	3.08	3.27	3.48	3.65
3.6	1.57	2.47	2.80	3.00	3.15	3.35	3.56	3.75
3.7	1.60	2.52	2.86	3.07	3.23	3.43	3.65	3.85

TABLE 47

Symbols for Wiring Diagrams



* For generator use same symbol with G in center.

Heights of Centre of Wall Outlets *

(unless otherwise specified)

Living-rooms	5′	6″
Chambers	5′	0″
Offices	6′	0″
Corridors	6′	3″
Height of switches (unless otherwise specified)	4′	0″

* Recommended by the National Electrical Contractors' Association.

STANDARD SYMBOLS FOR WIRING PLANS

Adopted by the Nat'l Elect'l Contractors' Ass'n and the Am. Inst. of Architects

Ceiling outlet; electric only*
Ceiling outlet; combination† — If gas only
Bracket outlet; electric only*
Bracket outlet; combination† — If gas only
Wall or baseboard receptacle outlet*
Floor outlet*
Outlet for outdoor standard or pedestal; electric only*
Outlet for outdoor standard or pedestal; combination†
Drop cord outlet
One light outlet, for lamp receptacle
Arc lamp outlet
Special outlet, for lighting, heating and power current, as described
Ceiling fan outlet
S^1 S. P. switch outlet
S^2 D. P. switch outlet
S^3 3-way switch outlet
S^4 4-way switch outlet
S^D Automatic door switch outlet
S^E Electrolier switch outlet

Show as many symbols as there are switches, Or in case of a very large group of switches, indicate number of switches by a Roman numeral, thus: S^1 XII, meaning 12 single-pole switches. Describe type of switch in specifications, that is, flush or surface, push-button or snap.

Meter outlet
Distribution panel
Junction or pull box
Motor outlet; numeral in centre indicates horsepower
Motor control outlet
Transformer
Main or feeder run, concealed under floor
Main or feeder run, concealed under floor above
Main or feeder run, exposed
Branch circuit run, concealed under floor
Branch circuit, concealed under floor above
Branch circuit run, exposed
Pole line

Riser

Telephone outlet; private service
Telephone outlet; public service
Bell outlet
Buzzer outlet
Push-button outlet; numeral indicates number of pushes
Annunciator; numeral indicates number of points
Speaking tube
Watchman clock outlet
Watchman station outlet
Master time clock outlet
Secondary time clock outlet
Door opener
Special outlet; for signal systems, as described in specifications
Battery outlet

Circuit for clock, telephone, bell or other service,‡ run under floor, concealed
Circuit for clock, telephone, bell or other service,‡ run under floor above, concealed

* Numeral indicates number of 16 cp. incandescent lamps.
† Upper numeral indicates number of 16 cp. incandescent lamps, lower numeral number of gas burners; e. g., $\frac{4}{2}$ indicates 4 incandescent lamps and 2 gas burners.
‡ Kind of service wanted determined by symbol to which line connects.

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